# An Analysis of Satellite-Tracked Drifter Observations Collected in the Grand Banks Region

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## ABSTRACT

Petrie, B and A. Isenor 1983. An analysis of satellite tracked drifter observations collected in the Grand Banks region. Can. Tech. Rep. Hydrogr. Ocean Sci. 39, P 69 + iii.

We present an analysis of 29 tracks taken by drifting buoys in the area defined by 39°-52°N and 43°-54°W. Successive buoy positions and the time interval between them are used to generate maps of the mean, maximum and standard deviations of currents in 1° by 1° squares. The buoys were drogued for the upper 24 m of the water column in general. Buoys which get on the Grand Banks remain there for an average of 101 (+ 70) d. For one buoy which remained on the Bank for 205 d, the wind did not appear to be a significant factor in determining its movement, accounting for only about 15% of the current variance. However, it is shown using idealized models how non-stationary conditions, position errors and aliasing can degrade the coherence between currents and wind.



## SOMMAIRE

Petrie B et A. Isenor, 1983. Une analyse des observations obtenues par bouées dérivantes suivies par satellite et recueillies dans la région des Grands Bancs. Can Tech Rep Hydrogr. Ocean Sci. 39, p. 64+iii.

Nous présentons une analyse des trajectoires de 29 bouées dérivantes dans la région comprise entre 39° et 52° de latitude N et 43° et 54° de longitude ouest. Les positions successives des bouées et les intervalles entre ces positions sont utilisés pour produire des cartes des moyennes, des maximums et des écarts-types des courants dans des carrés de 1° sur 1° Les bouées sont équipées de dragues à courant permettant des mesures dans les 24 m supérieurs de la colonne d'eau, en général. Les bouées qui atteignent les Grands Bancs y restent, en moyenne, pendant 101 jours (+ 70). Pour l'une des bouées, qui est restée sur le Grand Banc pendant 205 jours, le vent ne semblait par un facteur important du déplacement, ne permettant d'expliquer qu'environ 15% de la variance du courant. On a toutefois démontré à l'aide de modèles idéalisés comment des conditions non stationnaires et des erreurs de position et d'identification peuvent réduire la concordance entre les courants et le vent.

## INTRODUCTION

The increased activity in offshore oil exploration on the Grand Banks (note, the Grand Banks consist of St. Pierre, Green, Whale and Grand Bank) of Newfoundland (Fig. 1) has prompted more effort towards the analysis of archived oceanographic data from the region. Petrie and Anderson (1983) reviewed some of these data including six time series of satellite-tracked drifter observations. Since that document was completed approximately thirty additional drifter tracks have been made available. The analysis of these tracks is important since:

a) the observations can be used to map the mean currents and variance in a region where few direct measurements exist;

b) individual tracks can be used to test iceberg drift models;

c) it will allow dynamical processes such as wind-driven motions and exchanges of water between the Banks and Labrador Current to be investigated.

This report outlines some of the work carried out this past summer at the Bedford Institute of Oceanography which was made possible through financial support from the Office of Environmental Research and Development and Mobil Oil, Canada Ltd. The following section describes the data base and the methods used in the analyses. Maps of the mean, maximum and standard deviations of the velocity measurements will be presented next. In addition, we shall discuss features in the data such as the speed and path of the Labrador Current, the time spent by drifters on the Grand Bank and wind effects. The discussion of wind-current coherence will get special attention since it is an important consideration for offshore oil activity. When planning offshore operations, the combination of several environmental components, such as wind, waves, and currents, must be taken

MAP OF THE AREA

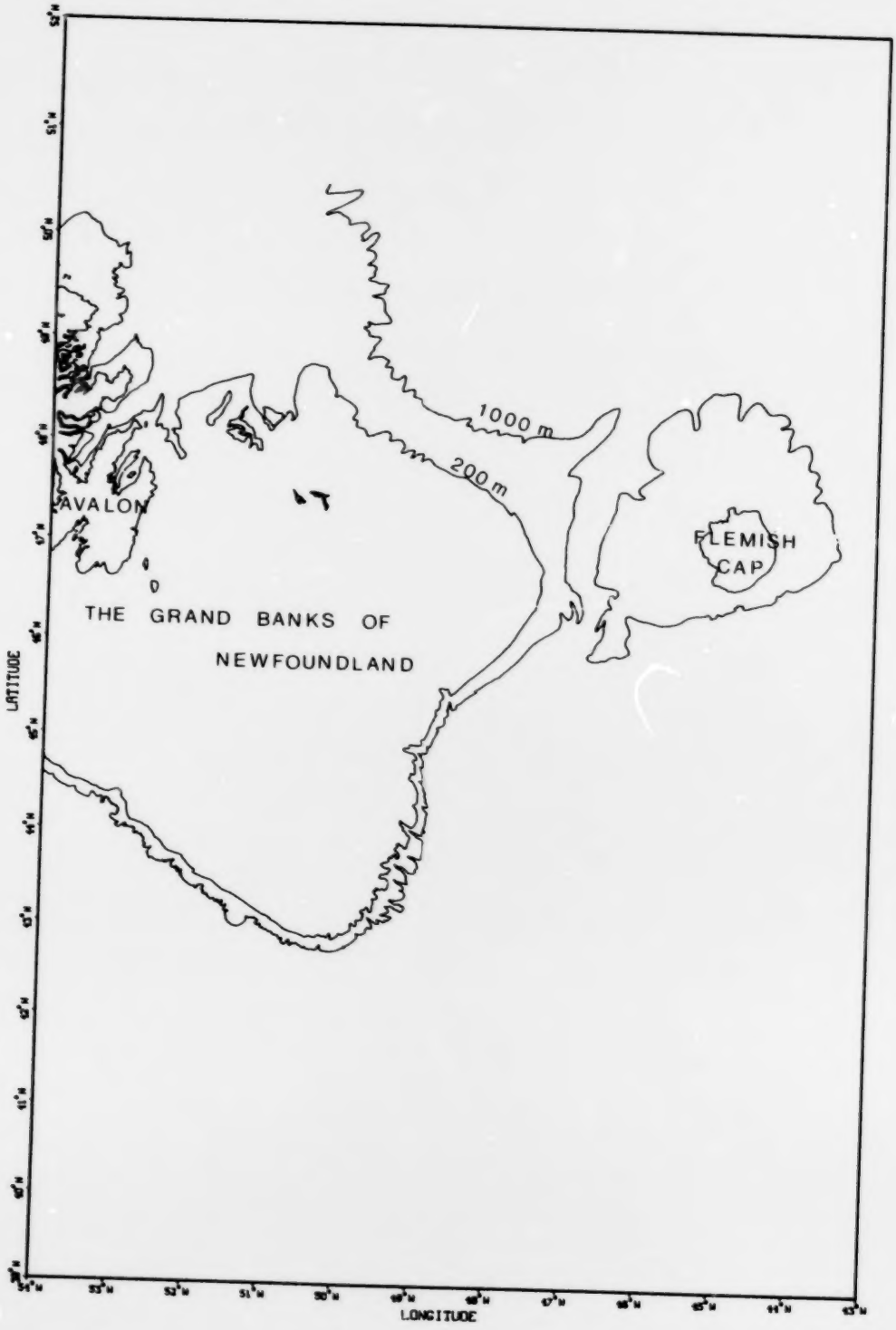



**Figure 1. The study area showing the 200 m and 1000 m isobath.**

into account. Does one plan on the basis that intense winds will give high waves and strong currents? Some of the data which we have analyzed can begin to address one of these questions, namely, what is the relationship of wind and currents.

To put the physical oceanography of the area in context, we present two figures. Figure 2 shows the circulation as depicted by Dinsmore (1972) in the Grand Banks area. The Labrador Current (a representative transport would be 4 x $10^6$ $m^3/s$) splits into two branches at about 49°N and 52°W, the inshore branch, carrying about 10% of the transport, flowing along the coast through Avalon Channel. The remaining portion Dinsmore shows as flowing along the 200 m isobath to about 49° W where it can again split into 2 branches, one continuing along the 200 m isobath through Flemish Pass, the other moving eastwards around Flemish Cap. Early investigators (see the review in Petrie & Anderson, 1983) had equal transports for these offshore flows but subsequent work indicated that the variability was great and all or none of the current could flow through Flemish Pass. Much of this circulation becomes entrained in the Gulf Stream Extension as shown in Figure 2. Dinsmore's circulation on the shelf features a very large cyclonic gyre on Grand Bank. Mann and Reiniger (unpublished work) compiled a circulation map (Figure 3) of a much broader area which shows basically the same pattern for the Newfoundland shelf except for the lack of a cyclonic gyre on Grand Bank. They show southward flow.

## OBSERVATIONS AND METHODS

### Sources

In 1976 the U.S. Coast Guard International Ice Patrol (I.I.P.) Service began a program of releasing satellite-tracked surface drifters in

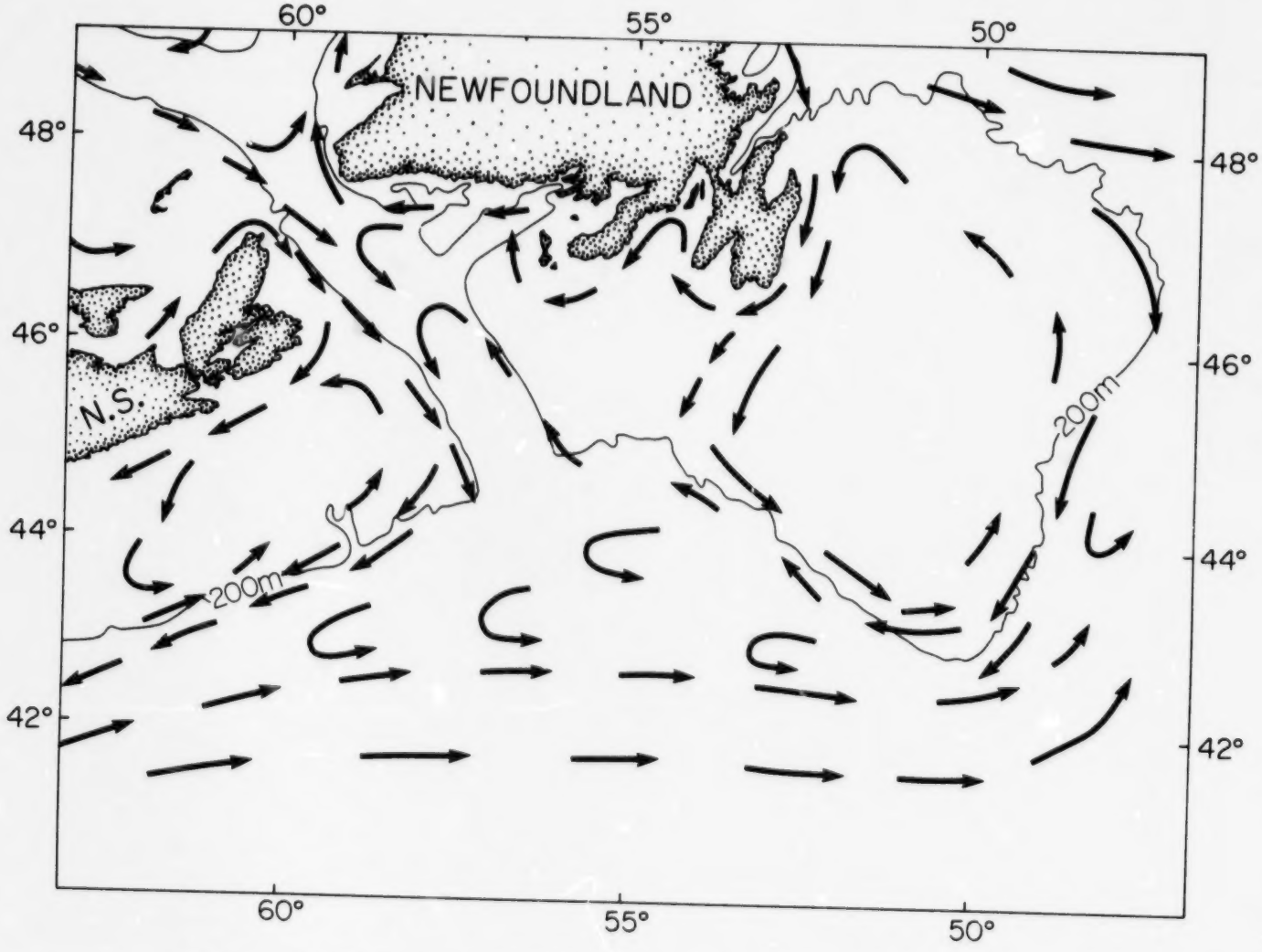



Figure 2. The circulation on the Grand Banks and adjacent areas as depicted by Dinsmore (1972).

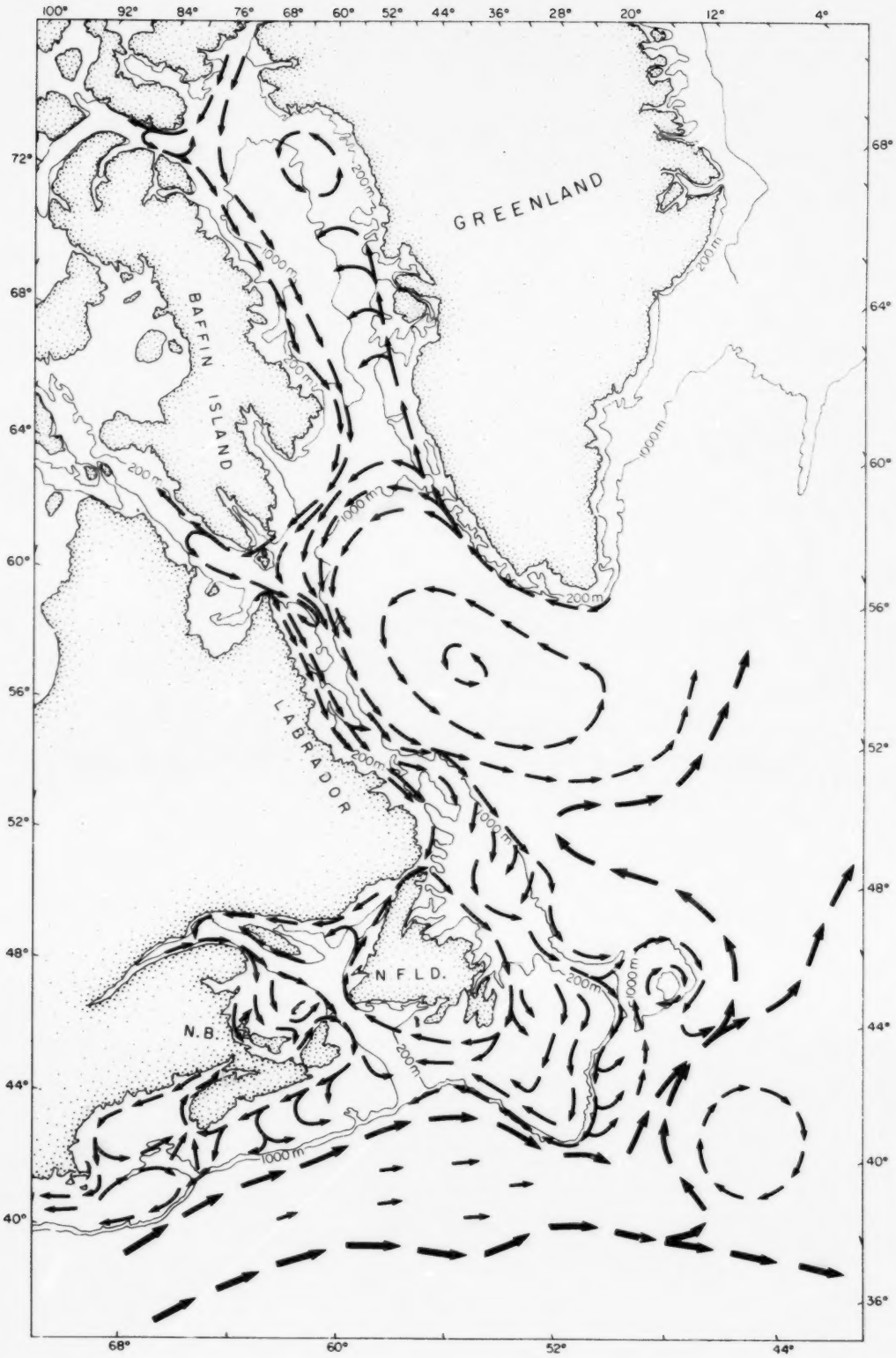



**Figure 3. The circulation in the Western North Atlantic as depicted by Mann and Reiniger (unpublished report).**

the Grand Banks region (Weir, 1979). The observations of near surface drift were made in support of their iceberg tracking and modelling studies which started as a result of the sinking of the Titanic in 1912. Twenty-four of the twenty-nine tracks we use in this report are from this ongoing work. Five of the tracks are from oil company studies. A list of the number of drifters used by year and source for 1976-1982 is given in Table 1.

## Sampling and Errors

The buoy used in the I.I.P. program has been described by Weir (1979). As best as we can determine, the standard configuration consists of a 13 m window shade drogue attached to the buoy by a 10 m tether. The data were obtained by using the RAMS or ARGOS positioning systems, the latter was used for intercomparison only. Data acquisition was irregular with an average of 3 positions/day. The indication is that a typical standard duration of a position fix is ±4 km (Kirwan et al., 1976; Murray, 1980, 1982). However, equipment problems in 1979 resulted in position errors of up to ±10 km (Murray, 1980).

## Data Handling

The raw data were acquired from I.I.P. in the form of computer printouts. A data base was set up and the raw data were edited by checking plots of the tracks and time series of current speeds based on successive positions of the buoys. The data from the oil companies were taken from plots of buoy tracks. About 0.5% of the data points were modified either by interpolation or, for particularly bad fixes, deleted entirely. An interpolated data set of one position at 1200 GMT for each day the

TABLE 1

Data Sources

| Year | Agency | Buoy Identification Numbers | Total Number |
|---|---|---|---|
| 1976 | Int. Ice Patrol | 177 | 1 |
| 1977 | Imperial Oil Ltd. | 1115, 1440, 46, 525 | 4 |
| | Int. Ice Patrol | 647 | 1 |
| 1978 | Int. Ice Patrol | 1224, 624, 731 | 3 |
| 1979 | Int. Ice Patrol | 2600, 2601, 2602, 2604, 2605 | 5 |
| 1980 | Int. Ice Patrol | 2610, 2613, 2630, 2632, 2633, 2634, 2636 | 7 |
| | Petro Canada | 370 | 1 |
| 1981 | Int. Ice Patrol | 2594, 2596, 2631 | 3 |
| 1982 | Int. Ice Patrol | 2637, 2638, 2639, 2641 | 4 |
| | | | 29 |

instrument was in the water was created from the raw observations. The comparison of the two time series was satisfactory. The interpolated buoy tracks are displayed in Appendix 1.

The area defined by 59°-52°N and 43°-54°W was chosen for detailed analysis. Daily mean currents based on successive positions of the buoys were calculated and grouped in 1° x 1° squares. The box number, the number of buoys which passed through, and the number of daily mean current vectors for each square are shown in Fig. 4. We make the observation that areas with weak currents tend to have a large number of data points while areas with strong currents tend to have fewer since, in the latter case, a drifter can enter and leave a 1° x 1° square in one day. This implies that the areas of strong currents did not have closed circulation patterns.

## RESULTS AND DISCUSSION

### Mean Currents

Fig. 5 shows the mean currents derived from the drift observations. Several features are noteworthy. The Gulf Stream and North Atlantic Current are quite evident as a strong flow to the east which then veers to the northeast with speeds of up to 1 m/s. This is similar to Richardson's (1983) analysis. The Labrador Current appears to parallel the 200 m isobath from north to south with speeds to about 0.25 m/s. Since this feature (see Petrie in Benoit and Mungall, 1983) is about 50 km wide, has horizontal excursions normal to the 200 m isobath of at least 60 km, and the resolution of the grid is at best 75 km, we expect the speed of the Labrador Current to be underestimated. The currents on the Grand Bank (<200 m) are somewhat haphazard and generally less than 0.10 m/s with one notable exception being on the outer edge of the Grand Bank which had few

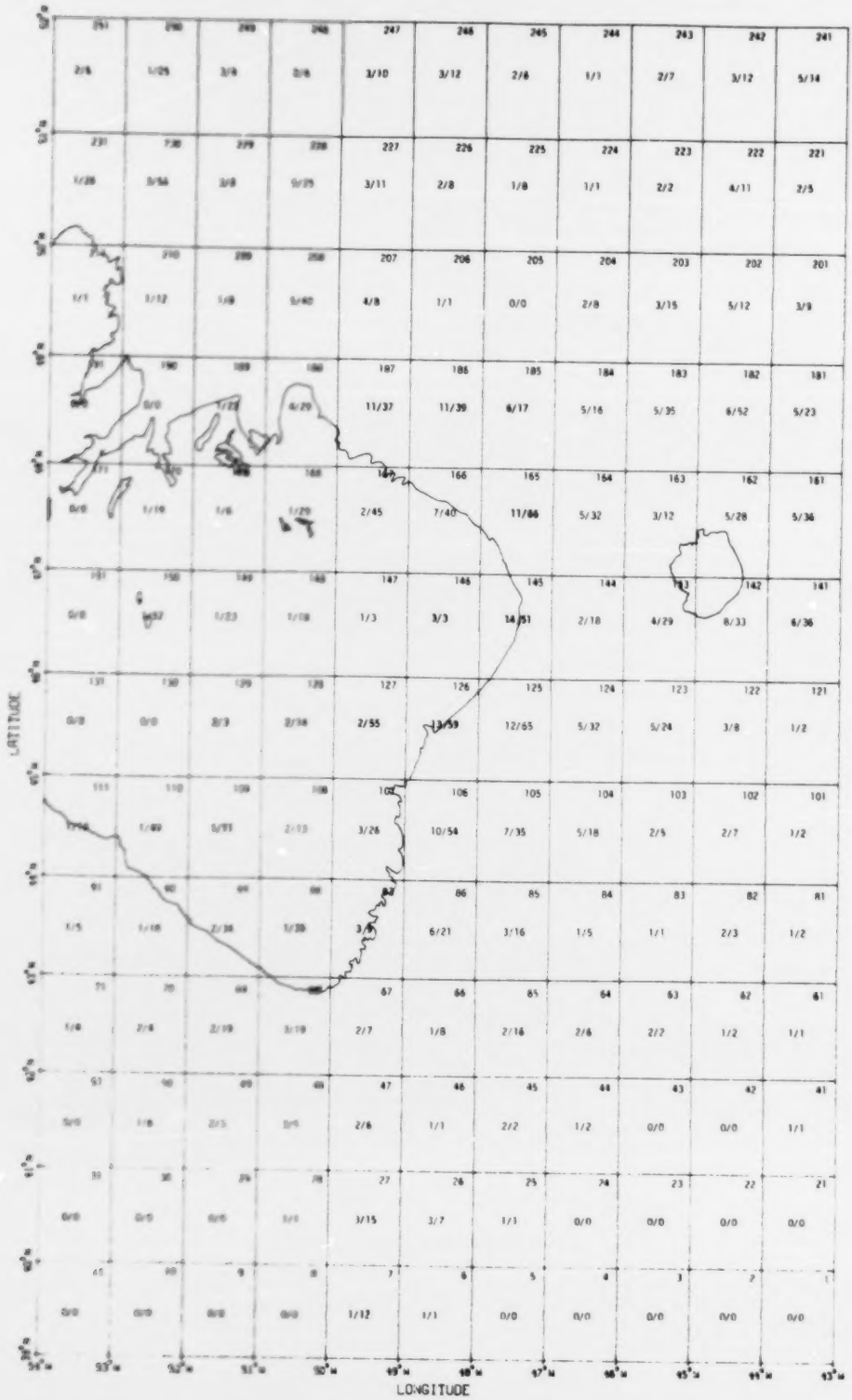



Figure 4. The study area divided into 1° x 1° squares each of which contains a identity number in the upper right hand corner and the number of drifters which entered each square/the number of daily mean current vectors for each square.

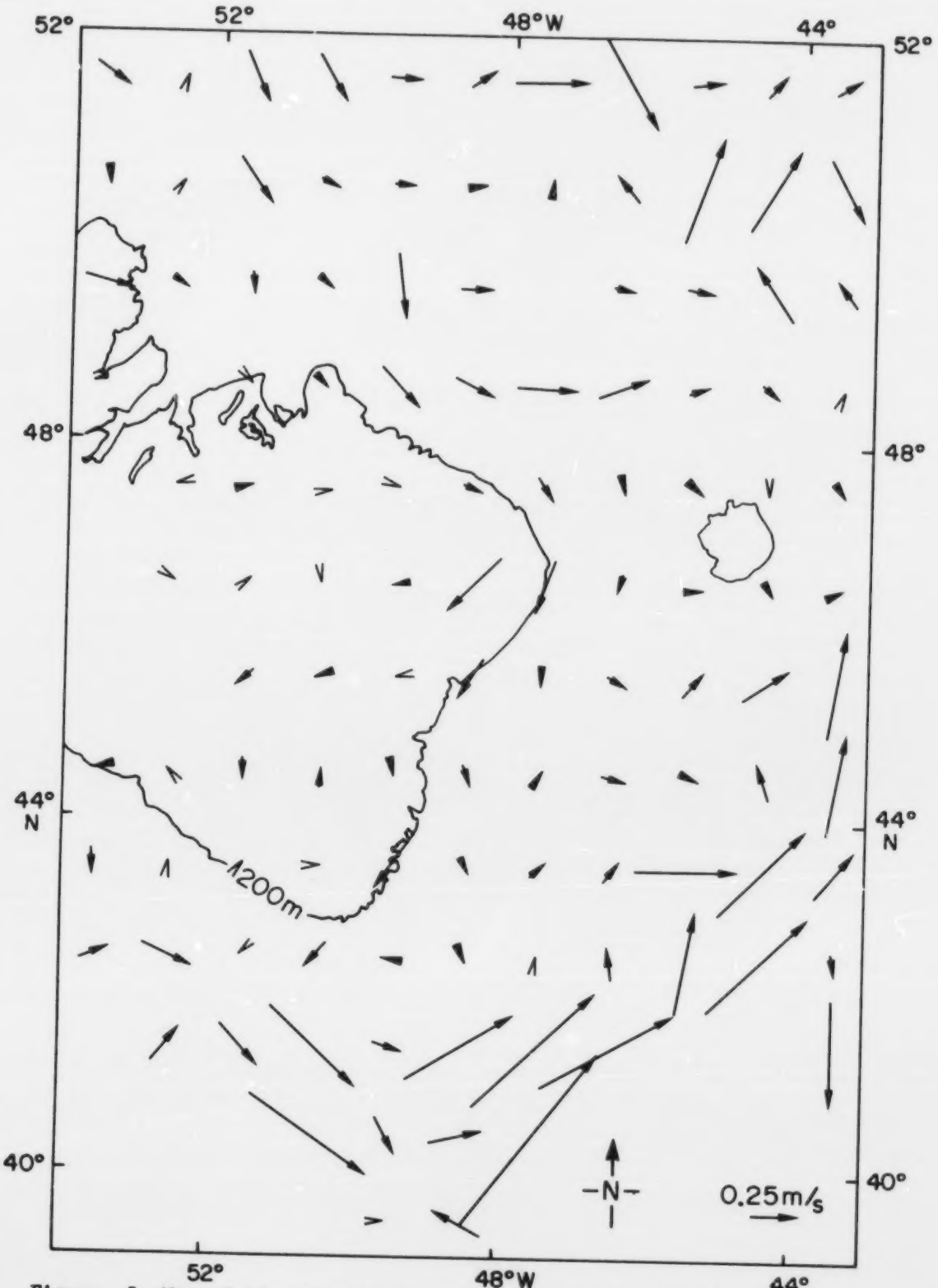



Figure 5. Map of the mean current vectors for each 1° x1° square. An open arrowhead signifies a current between 0 and 0.05 m/s. A solid arrowhead signifies a current between 0.05 and 0.10 m/s.

samples (box 146, see Fig. 4) and perhaps was influenced by the Labrador Current.

Standard deviations of the currents

The standard deviations of the currents were determined along the principal axes (Fofonoff, 1969) from a minimum of 3 daily mean vectors. These axes are defined as those for which the covariance of the two current components is zero. The axes may be used to generate an ellipse which characterizes the behaviour of the variable flow. The ellipses (Fig. 6) show the same behaviour as the mean currents. The variance is least on the Grand Bank, greater in the Labrador Current, and greatest in the Gulf Stream-North Atlantic Current region. Figure 7 shows the ellipses superimposed on the mean currents. North of 48°N the ratio of the mean to the standard deviation of the current is 0.84. Whereas, on the shelf (inside the 200 m isobath, excluding Flemish Cap) the ratio is 0.45. The areas where this ratio is greater than or less than 0.5 are shaded in Fig. 8. Regions where the mean current is at least one half of the standard deviation are mainly north of the Grand Bank and in Flemish Pass. The Grand Bank, Flemish Cap and south of Flemish Pass generally show the mean current as less than half of the variable flow. These results have implications for iceberg drift prediction since, in areas where the mean dominates, one might expect to be able to make a drift forecast farther into the future. In our case (Fig. 7 and 8), however, the statistics should be viewed as only giving an indication of the partition of current between mean and variable flows.

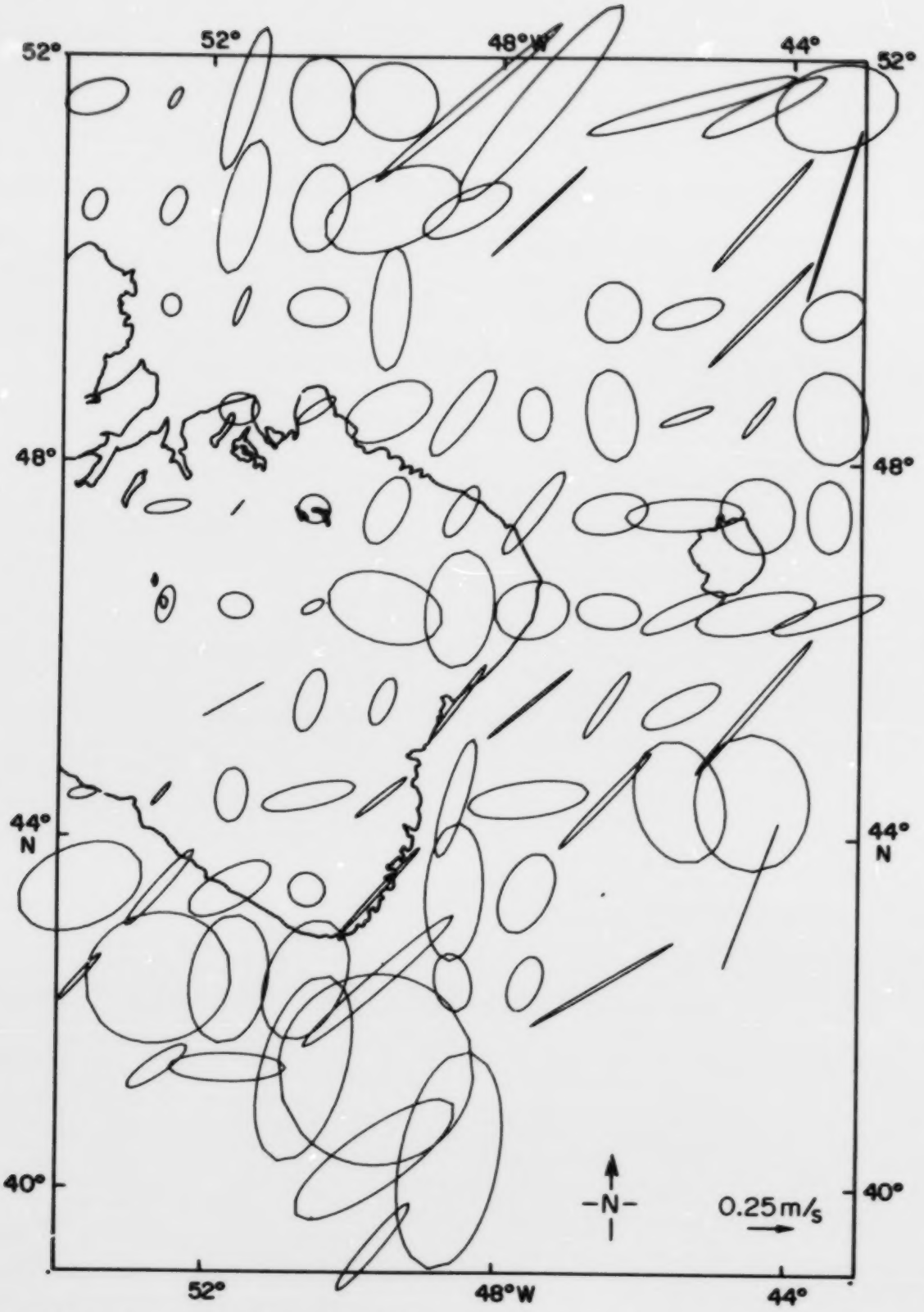



Figure 6. Map of the standard deviations of current resolved along the principal axes for each 1° x 1° square.

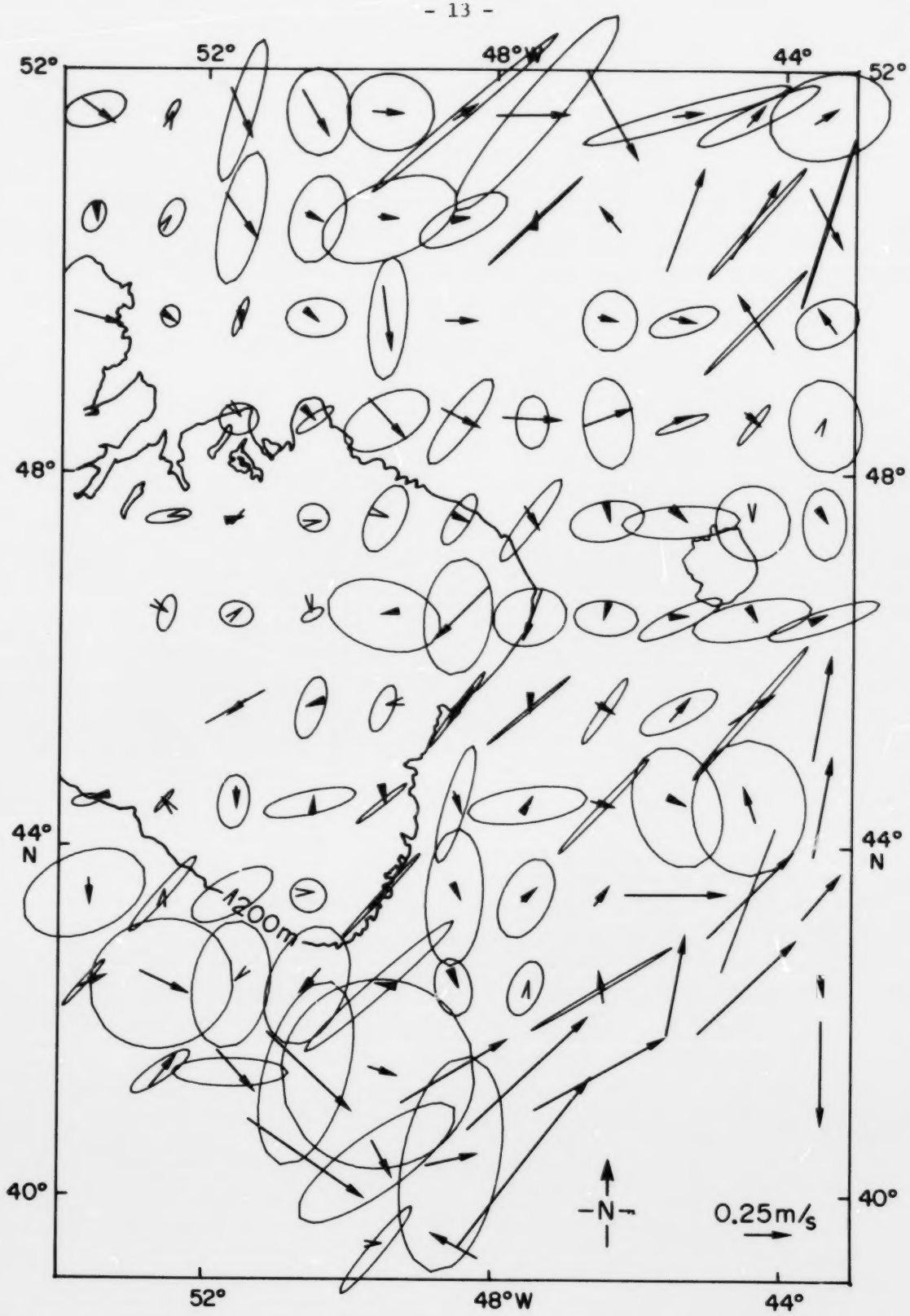



Figure 7. Combination of the mean current vectors (Fig. 5) and the standard deviations of current (Fig. 6). For some 1° x1° squares there were insufficient data, 2 points or less, to calculate the standard deviations.

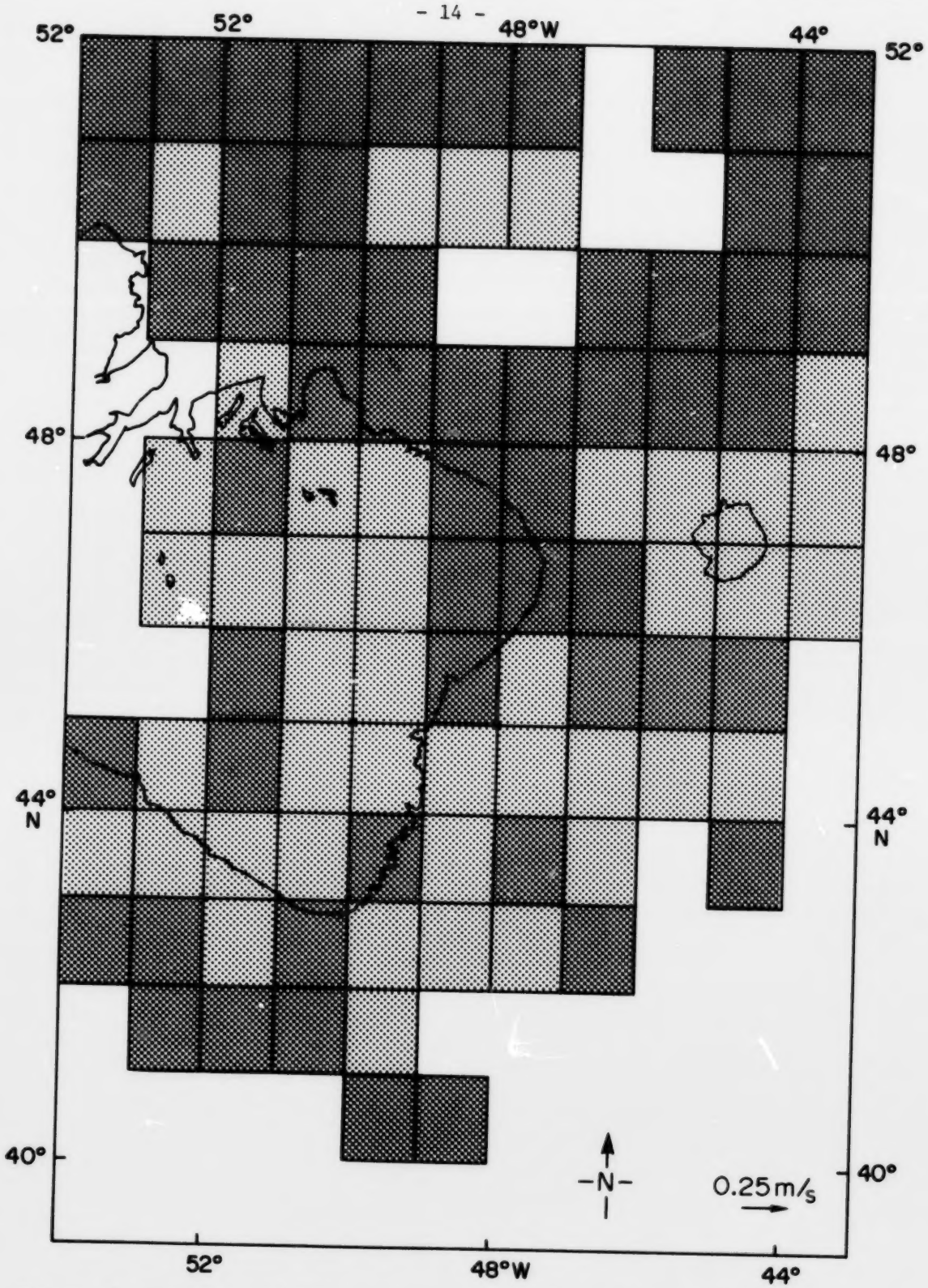



Figure 8. The ratio of the mean current to the standard deviation is contoured. Dark areas correspond to regions where the ratio is greater than 0.5 and light areas to regions where it is less than 0.5. In unshaded areas there were not enough data to determine the ratio.

Maximum currents

A map of the maximum currents is shown in Fig. 9. On the Grand Bank, the maximum daily mean current observed was 0.75 m/s. The larger maxima occurred near the outer edge of the Bank and decreased substantially in from the 200 m isobath. The Labrador Current, i.e., along the 200 m isobath, showed a maximum current of slightly greater than 1 m/s. The Gulf Stream region had a maximum of about 1.2 m/s.

Drifters in the Labrador Current

There were 7 buoys which, over a large part of their track, appeared to be confined mainly to the offshore branch of the Labrador current and moved parallel to the 200 m isobath. Six were launched near 49°N, 50°W and one near 47°N, 47°W. As we noted previously, combining all the data for a 1° x 1° square near the 200 m isobath might give low values of the mean velocity of the Labrador Current since it is quite narrow relative to our spatial resolution. This is easily seen by examining the square defined by 44°-45°N, 48°-49°W in Fig. 10. For this analysis, we examined only the segment of the buoy track which had a southward component. The map of mean currents is shown in Fig. 11. Qualitatively, it is similar to the map of Fig. 5 but the magnitudes are substantially greater. The tendency of the Labrador Current to parallel the 200 m isobath is evident.

Drifters on the Grand Bank

There were 5 drifters (Table 2) which spent time on the Grand Bank, that is, within the 200 m isobath. Four were launched outside the 200 m isobath and number 2596 was deployed just off the Avalon Peninsula. Buoys

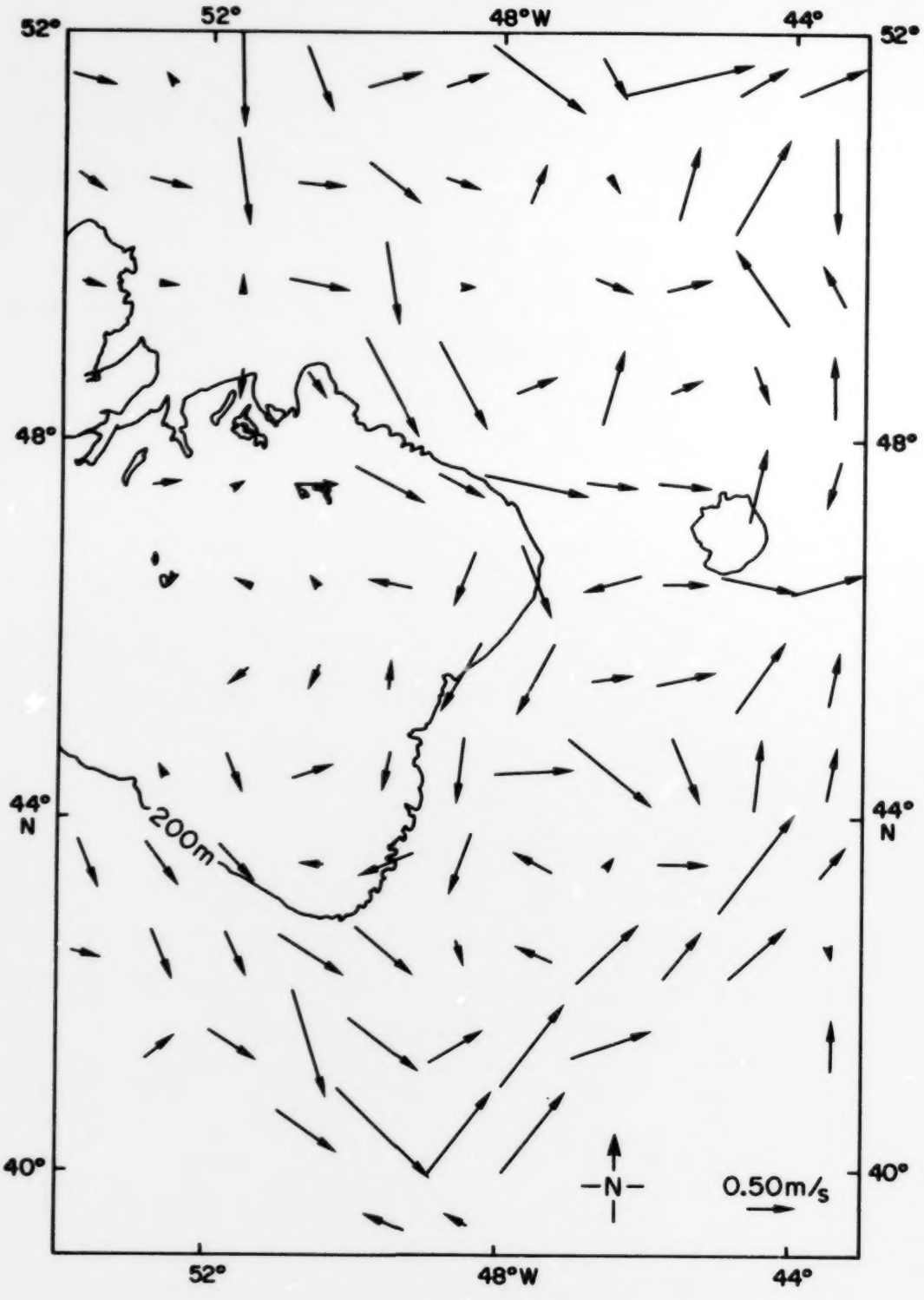



Figure 9. Map of the maximum currents for each 1° x 1° square.

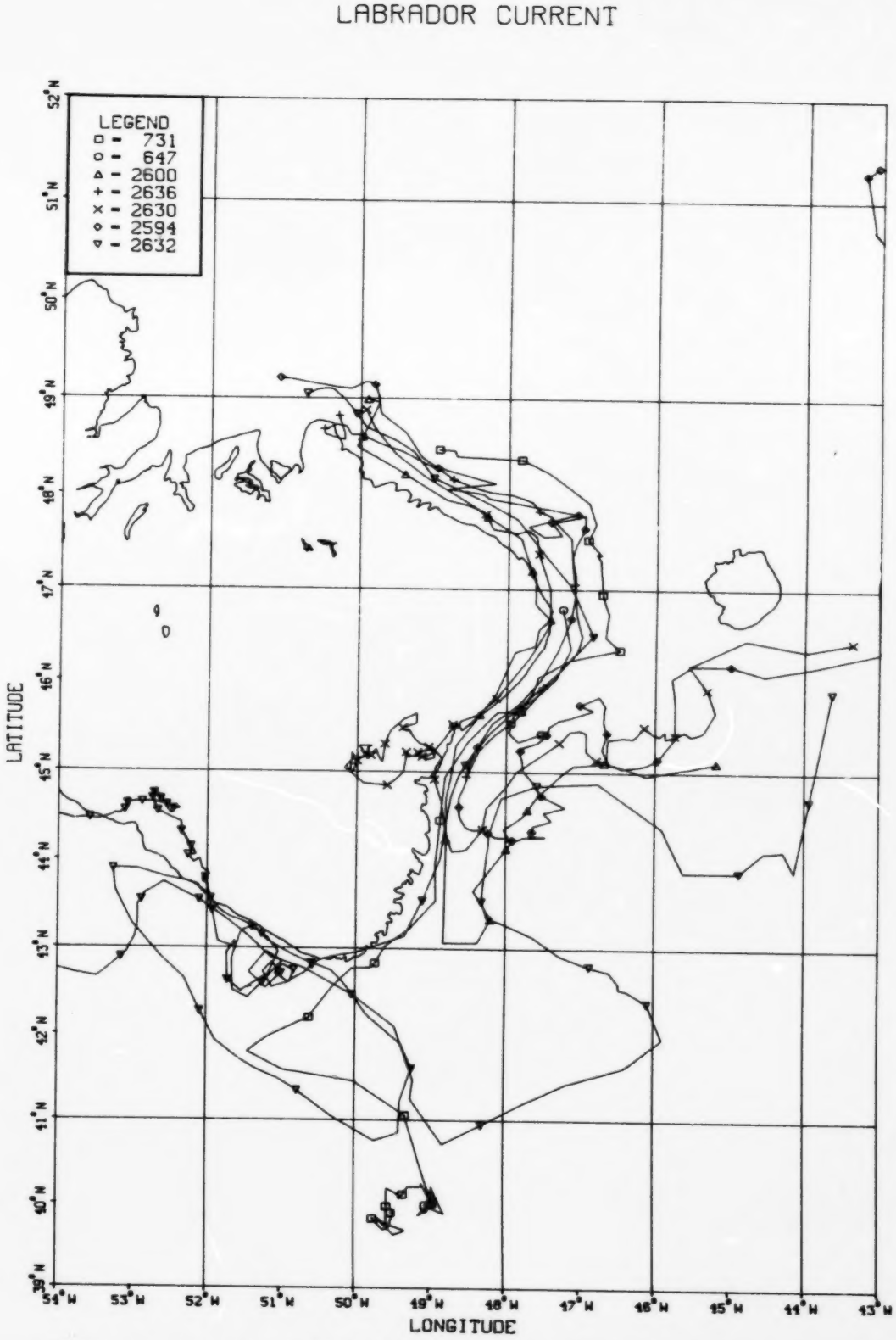



Figure 10. Tracks of the 7 drifting buoys which followed the Labrador Current.

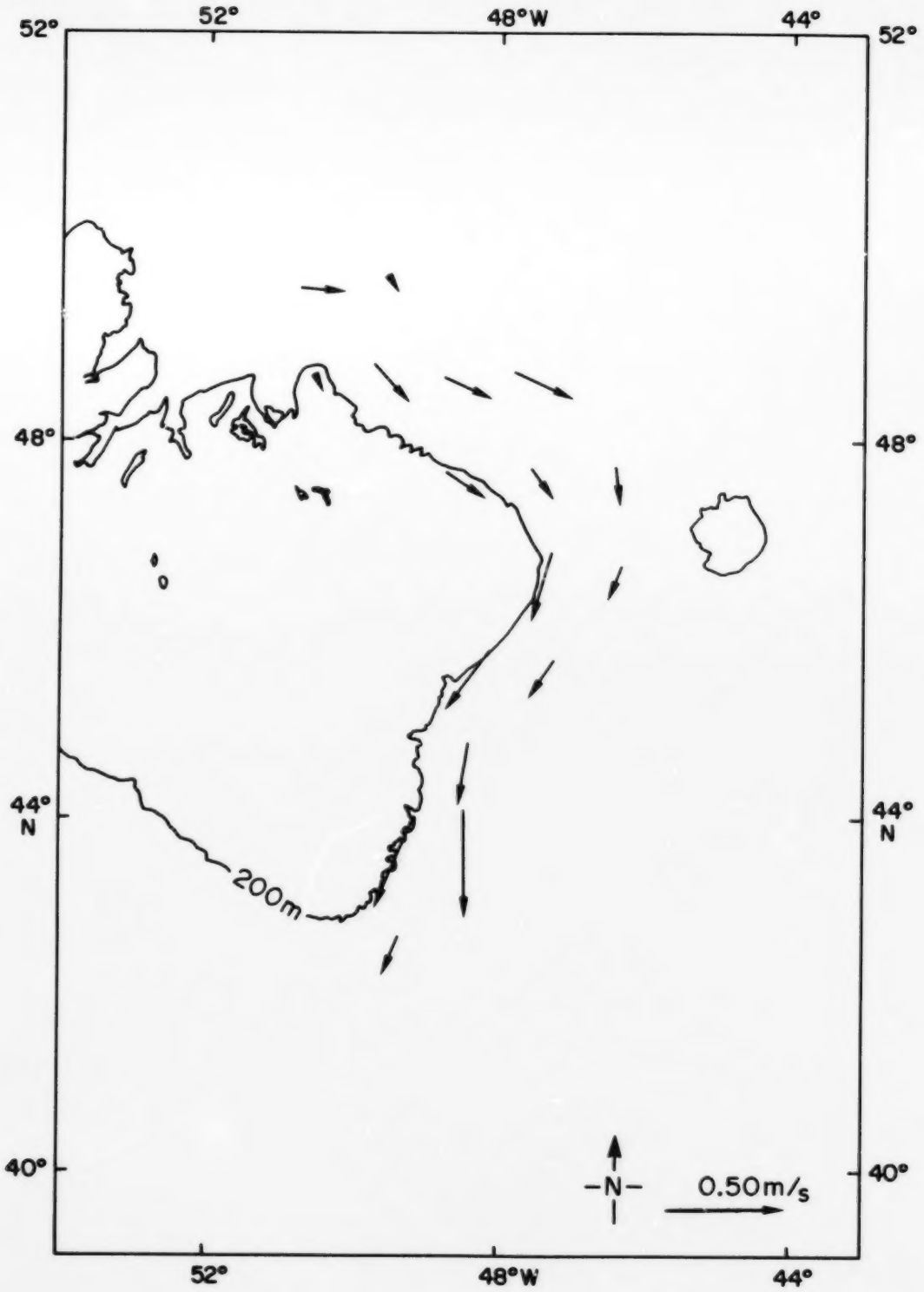



Figure 11. Currents derived from the tracks of the buoys shown in Figure

TABLE 2

Drifters on the Bank

| ID Number | Year | First Day on Bank (Julian Day -Date) | Day Off Bank | # of Days |
|---|---|---|---|---|
| 2605 | 1979 | 61 (March 2) | 199 (July 18) | 138 days |
| 2630 | 1980 | 101 (April 10) | 164 (June 12) | 63 days |
| 2632 | 1980 | 187 (July 5) | 253 (September 9) | 66 days |
| 2633 | 1980 | 284 (October 10) | 317 (November 12) | 33 days |
| 2596 | 1981 | 113 (April 23) | 318 (November 14) | 205 days |
| | | 322 (November 18) | *328 (November 24) | 6 days |

*The buoy, while still on the Bank, was picked up on this date.

2630 and 2633 appeared to be in the fast moving Labrador Current before moving onto the Bank. Buoy 2633 did not appear to be in this current before drifting inside the 200 m isobath but did enter the stream after leaving the Bank. There was a 4 d data gap between the first and second positions of buoy 2605 during which it moved inside the 200 m isobath. The number of days spent within the 200 m isobath ranged from 33 to 205 with a mean of 101 d and a standard deviation of 70 d.

Wind Effects

Our first investigation of the drifter data for wind effects consisted of comparing the movement of the buoys with the meteorological conditions described by weather charts or by the Marine Weather Log Report for the times when the drifters (Table 2) entered or left the Grand Bank. There was not any obvious connection between buoy movement and wind described by either source. Complete or nearly complete wind data measured from rigs on the Grand Bank were available for three (2632, 2633, 2596) of the drifters listed in Table 2. However, drifter 2632 was at best, more than 400 km from the rig site during its time on the Bank and buoy 2633 spent only 33 days on the shelf. Fortunately, drifter 2596, which spent the most time (205 d) on the Bank, was always within 300 km of the wind measuring site and had 194 d (April 22-Nov 1) during which contemporaneous wind and position data were available. Therefore, the second approach we took was to compare the daily mean currents computed from the track of I.I.P. buoy 2596 to the daily mean winds observed on an oil drilling platform (46°48'N, 48°42'W). Buoy 2596 had its drogue tethered between 10 and 20 m, had an average of 4.5 positions/day, and had 14 d without a reported position. The meteorological data return was greater than 98% for the

period in question. Missing data were replaced by interpolated values.

At this point, we do not have an independent check of the accuracy of rig winds. However, an intercomparison (in preparation) of winds measured from different rigs shows good agreement. Moreover, our experience with synoptic weather charts indicates that geostrophic winds derived from them would offer no distinct advantage in this area. Efforts are being made this winter to improve the charts for the region by mooring 3 buoys which can measure barometric pressure and transmit the data to land-based weather stations by satellite link. This will allow some independent checking of rig winds.

Figure 12a-d shows plots of daily mean wind velocity against current velocity. There does not appear to be any striking dependence of current and wind speed. In fact, it appears that, regardless of the wind, most current observations appear to fall between ±0.1 m/s. Table 3 confirms this conclusion. Wind (U represents eastward wind, V northward)can account for about 5% of the variance of the u (eastward) component of current or about 10% of the variance of the v (northward) component. It is interesting to note that the relationship between the cross components of wind and current is as one would expect if the response were in the Ekman sense. That is, the simple correlation coefficient for (u,V) is positive and $b_2$ is positive. While, on the other hand, the correlation coefficient for (v, U) is negative and $b_1$ is negative as well. If an Ekman model contained the appropriate physics for the situation we might expect, say for a 10 m/s wind and a layer of 50 m depth, coefficients of order 0.003, as observed. However, we do note that the colinear coefficients are of comparable magnitude as well. For all this speculation about Ekman momentum balances, it must be reiterated that only 10% or so of

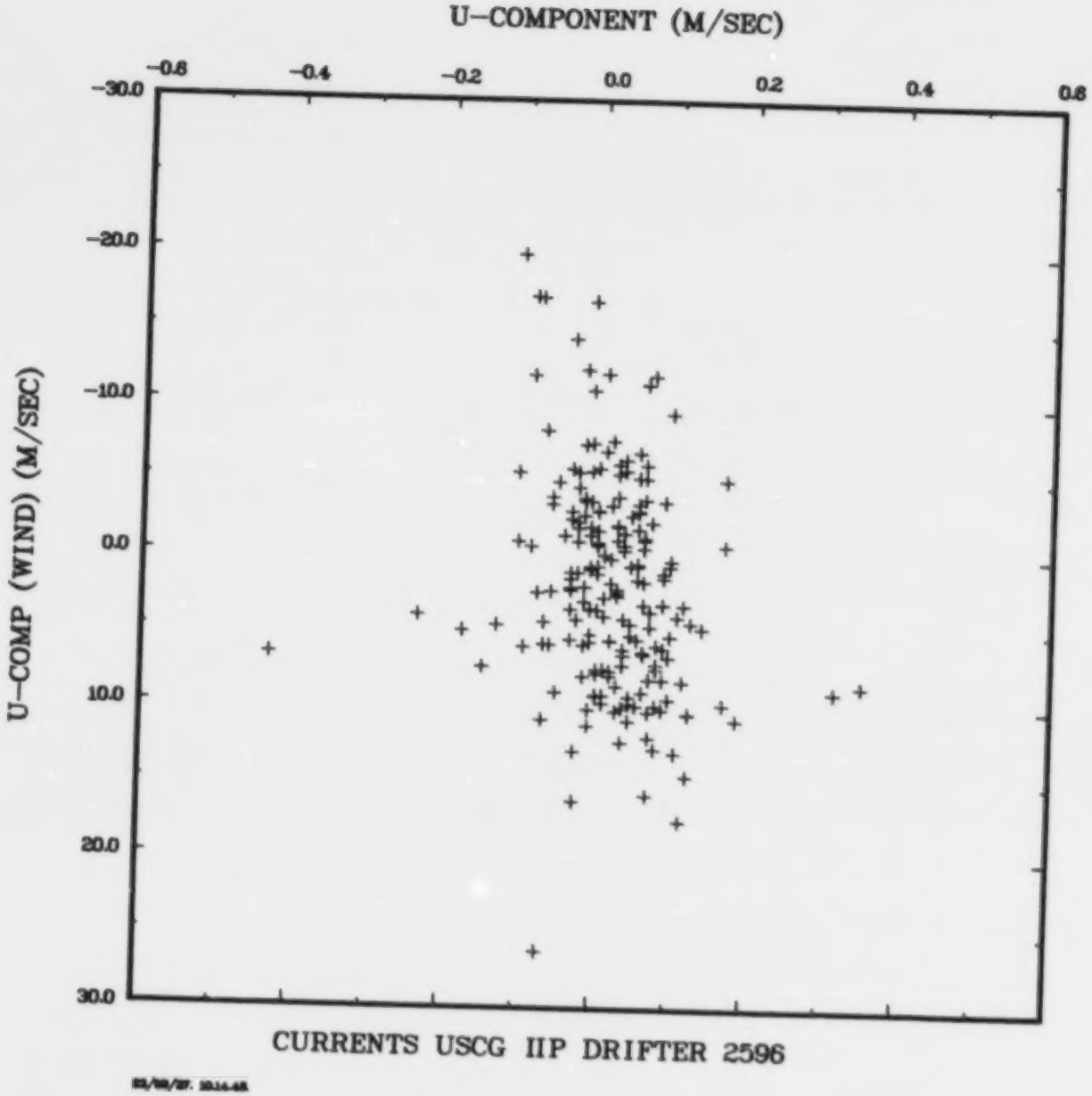
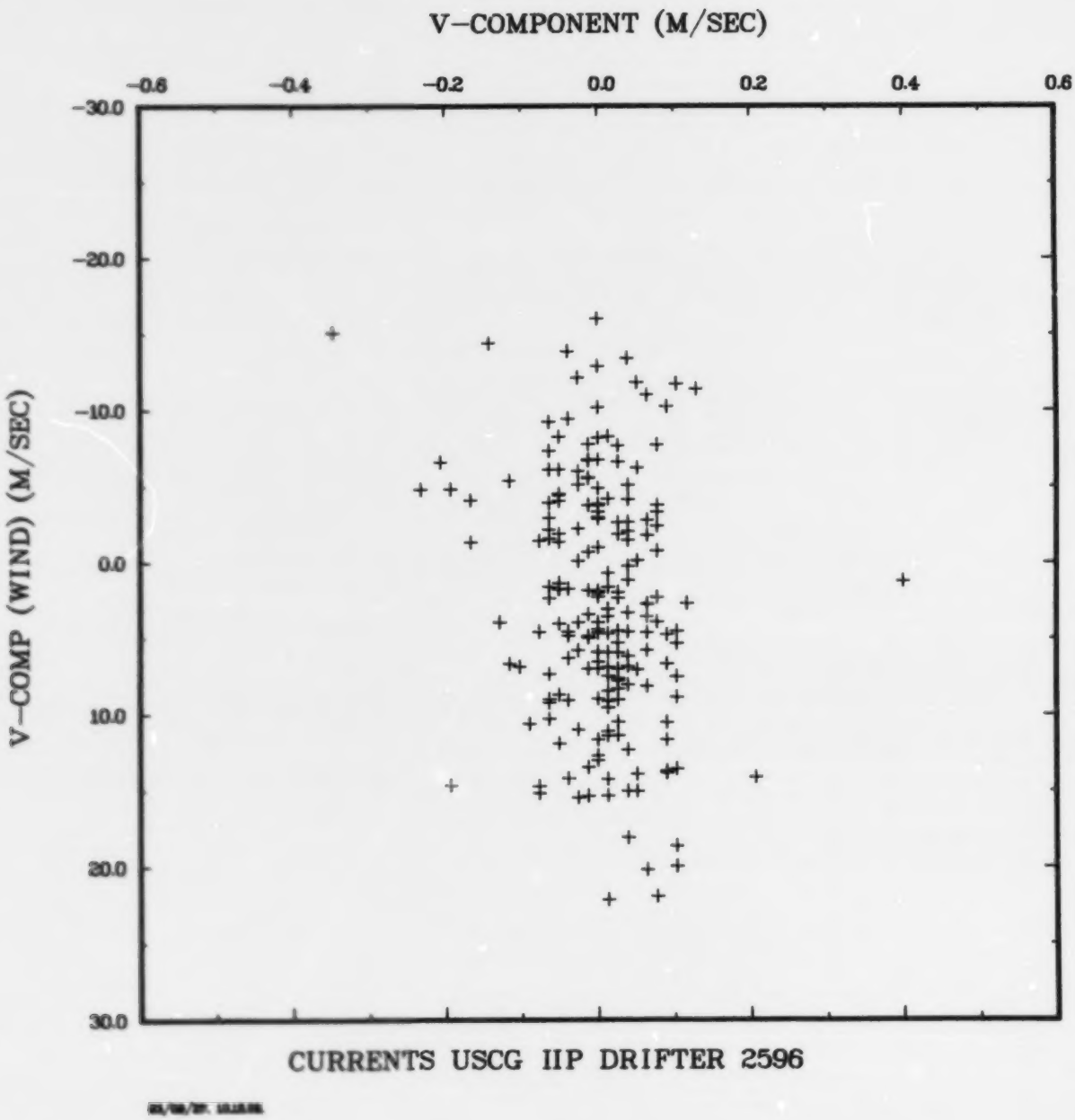
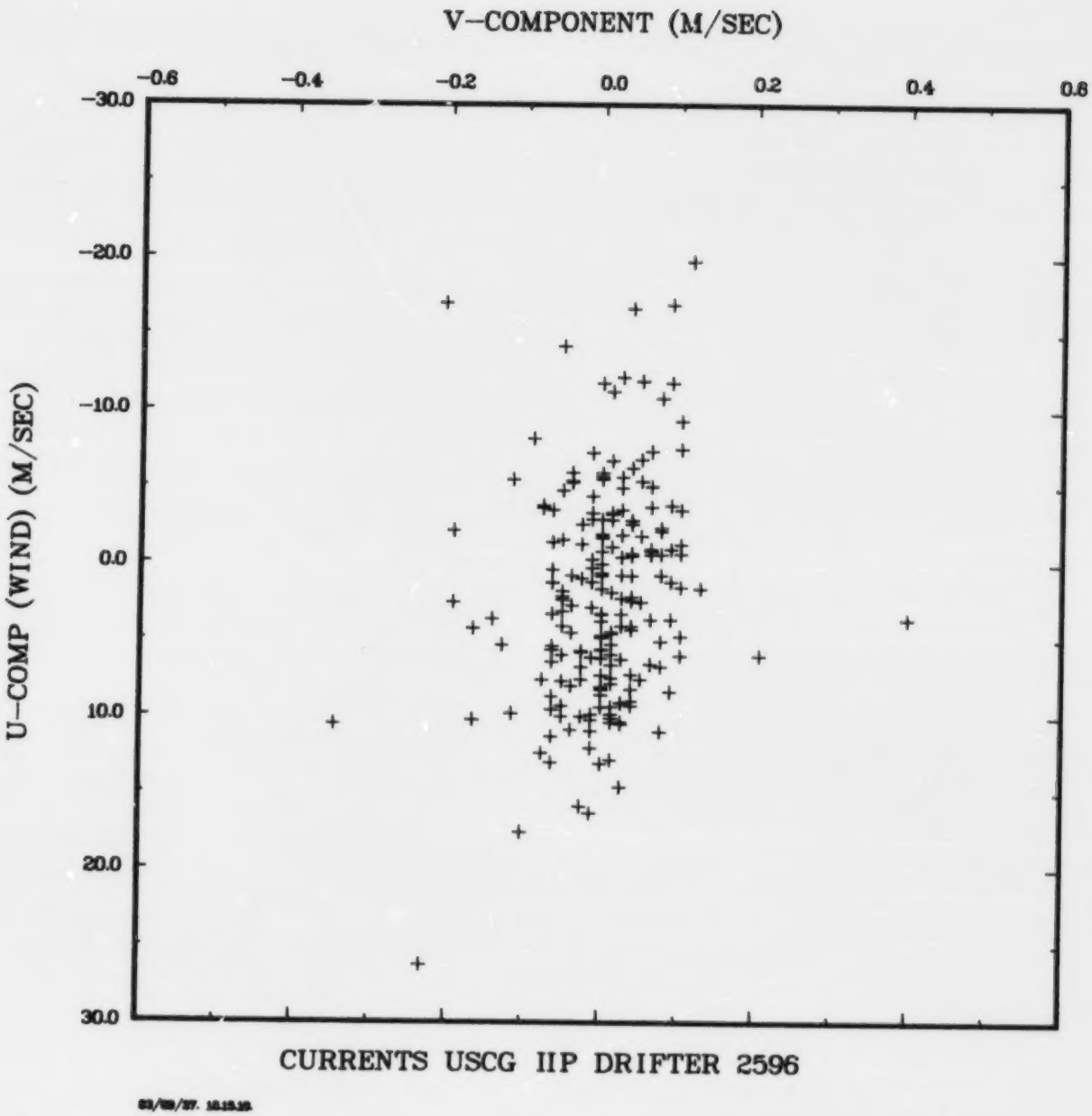


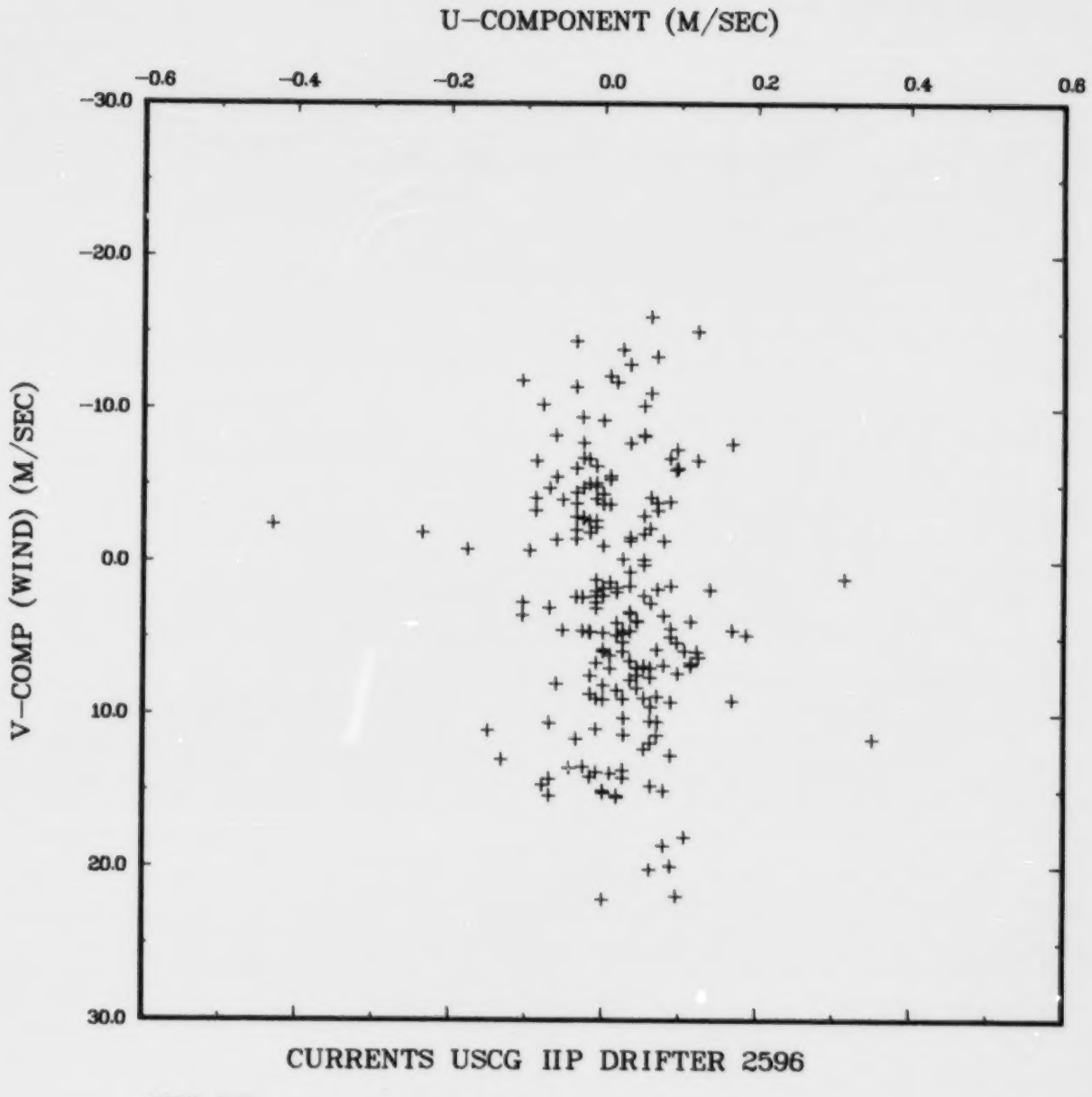

Figure 12. Two parameter plot of a) the eastward wind and current;




b) the northward wind and current;




c) the eastward wind and northward current; and,




d) the northward wind and eastward current.

TABLE 3

Relationship between daily mean winds and currents on the Grand Bank based on the drift track of I.I.P. drifter 2596.

Simple Correlation

| | u | v | U | V |
|---|---|---|---|---|
| u* | | -0.02 | 0.20 | 0.13 |
| v | | | -0.22 | 0.20 |
| U | | | | 0.22 |
| V | | | | |

Variance $(m/s)^2$

| $u^2$ | $v^2$ | $U^2$ | $V^2$ |
|---|---|---|---|
| $6.1 \times 10^{-3}$ | $5.5 \times 10^{-3}$ | 50 | 65 |

Multiple correlation (r) and regression

| | r | $b_0$ | $b_1$ | $b_2$ |
|---|---|---|---|---|
| u | 0.23 | 0.012 | 0.0021 | 0.0010 |
| v | 0.32 | 0.002 | -0.0026 | 0.0023 |

where $u, v = b_0 + b_1U + b_2V$

*lower case letters apply to current, upper case to wind components.
u and U positive eastwards, v and V positive northwards

current variance is accounted for by wind. Does this mean that the wind doesn't appreciably affect the currents on the Grand Bank? Not necessarily , there are complicating factors. For example, when the buoy was deployed (April) the water column was essentially unstratified. During the next few months a highly stratified layer developed which was well on its was to breaking down at the end of the data period (Nov.). Conditions were not stationary. Tides, inertial period motions and position inaccuracies could also affect the comparison between winds and currents, possibly obscuring their relationship. We shall consider these in turn.

To determine the effect of a time varying mixed layer depth, we considered several simple models of the ocean response to wind forcing. Perhaps the simplest of these consisted of an Ekman response to wind but with the upper layer (Ekman layer) varying in depth. Thus, we have

$$u = \tau(y)/(\rho f h) \tag{1}$$

$$h = h_0 - h_1 \sin \omega t \tag{2}$$

where u is the current, $\tau$ the wind stress, $\rho$ the water density, f the Coriolis parameter, h the Ekman depth, $\omega$ the frequency, and t the time. For $h_0 = 80$ m, $h_1 = 60$ m, $\tau(y) = \tau_0 \sin \gamma t$ with $\gamma$ corresponding to a single period in the band of 3-7 d, and $\omega$ corresponding to a 420 d period (this represents the Ekman layer changing from 80 m to 20 m and back to 80 m in a 210 d span), the correlation coefficient between wind and current, given perfect data, would be 0.92 after 210 d. Thus, even if our observations were ideal the maximum correlation would not be 1.0 but would be degraded. We considered a set of other factors such as tides, inertial waves or wind components at several frequencies which could modify the results.

At this stage will mention only two additional results. The first of these was a single layer model of the ocean with h varying as in equation (2),

driven by the sum of north-south and east-west winds with stress equal to 0.2 Pa and periods of 3, 4, 5 and 6 d. That is, there were winds at four frequencies acting together. Note, changing stress by a factor of 5 didn't alter the results appreciably. The M2 tide is included in the calculation of the correlation coefficients with an east-west amplitude of 0.10 m/s and a north-south amplitude of 0.05 m/s. These values are representative of conditions on the Grand Bank. The momentum equations are integrated, the currents averaged over 24 hr (this is where the tide can degrade the correlation), and compared to the similarly averaged winds. Acceleration, Coriolis and wind stress terms constitute the momentum balance and thus allow for the generation of inertial period motions as well as an Ekman response. The model does not allow for the presence of a coastline. After 210 d the correlations were -0.87 for v*U, 0.05 for u*U, 0.07 for v*V, and 0.87 for u*V.

For a smaller $h_1$ the correlation increases while for a large $h_1$ the correlation decreases. For example, with $h_1$ = 70 m, the correlation is -0.80 for v*U. We conclude then that the changing depth of the upper layer, where for the greater part the buoy's drogue would be located, and contamination by tides and inertial period motions can have a small but appreciable effect on the apparent relationship of the wind and current. In reality, neither the pynocline nor the wind stress varies as smoothly as in the case we have just considered. Moreover, there are other factors, such as low frequency waves propagating into the region from other areas, sharp shifts in wind amplitude or direction which may result in sudden changes in inertial period motions operating as well. These, combined with irregular (and noisy) data sampling, could result in modified or aliased data and lead to further degrading of the wind-current correlation. We shall consider errors in the data next.

Noise due to Position Errors

The error, that is, the standard deviation, of a position fix was quoted earlier as being about ±4 km on average or as much as ±10 km during 1979. We would like to consider by how much such an error could degrade the correlation of current, derived from successive fixes, with wind. Consider the following simple model:

$$U_i = F(W_i) + N_i$$

where $U_i$ represents the ith measurement of current estimated from successive fixes, $w_i$ is the corresponding wind observation and $N_i$ is the noise due position errors. The noise is not correlated either with the wind or the current. We further simplify the problem assuming that the current is linearly related to the wind so that as the noise approaches zero, the correlation goes to 1.0. Thus, the correlation r is given by

$$r = (\Sigma U_i^2/(\Sigma U_i^2 + \Sigma N_i^2))^{1/2}$$

Given that the standard deviation of a position fix is ±4 km then it can be shown that the standard deviation of the velocity based on successive fixes is:

$\sqrt{2}$*(±4 km/time between fixes).

We shall consider that the data set consists of 1 fix per day and that the fixes are separated by 24 hours. Thus, the variance of the noise would be $2(4\times10^3/86400)^2 = 4.3 \times 10^{-3}$ $m^2/s^2$.

Combining the noise variance with a typical current variance of $6 \times 10^{-3}$ $m^2/s^2$ (see Table 3) gives an optimum correlation of 0.76. This is quite a significant effect on the magnitude of the correlation coefficient. Combining this reduction with that estimated from our simple model of nonstationary conditions would give an optimum correlation of 0.63. That

is, we could at best expect to account for about 40% of the current variance. If the position errors were as large as ±10 km as they were in 1979 we would expect that noise alone could degrade the correlation to 0.43.

## Concluding Remarks

There have been several worthwhile results from this analysis. The maps of mean, maximum and fluctuating currents have been useful to derive. Perhaps, though, our preliminary examination of the relationship between current derived from successive fixes of a Lagrangian drifter has been more interesting. The initial result, that wind did not seem to affect the currents strongly, became less certain after we applied some simple models to address the problems of nonstationary conditions, aliasing due to tides and inertial period motions, and noise in the data. The latter proved to be especially effective in degrading the correlation. It seems that this problem, the coupling of wind and currents, deserves additional scrutiny. One task would be to confirm by independent means that the rig-based measurements of wind speed and direction are sufficiently accurate. Our investigation has been limited to a single drifter and even though it was an exceptionally long record, additional observations would yield improved statistics. But before deploying more buoys, we would require that better and more frequent position fixes be available. This now seems possible. Richardson (1983) indicates that ARGOS positioning system provided 4-5 fixes per day with an accuracy of 0.1-0.2 km. Recent experience at Bedford Institute (Charles Tang, pers. comm.) indicates 6-7 positions of 0.1-0.2 km accuracy are possible. Tang, whose measurements were made in deep water where tidal currents would be very small, was able to extract inertial

period motion (horizontal displacement amplitude of about 2 km) with ease. Therefore, we could expect to be able to reduce the aliassing of the data due to energetic, high frequency motions. Before proposing any new observation program, however, we intend to complete our analysis of the wind-current coupling where the current observations in this case are based on fixed point measurements.

## ACKNOWLEDGEMENTS

The data which made this report possible were provided, for the greater part, by the United States Coast Guard, International Ice Patrol. In particular, we would like to thank Lieutenant Commander Alan D. Summy for all of his efforts. Randolph Currie, John R.N. Lazier and Charles K. Ross generously gave us computer programs which formed the core of our statistics and plotting routines. Jacques Benoit, Mobil Oil, Canada Ltd., and Christian Mungall, Mobil Research and Development Corporation, were very helpful and provided useful suggestions and data throughout the course of this project. Anthony Isenor acknowledges the financial support of the Department of Energy, Mines, and Resources, Office of Environmental Research and Development and Mobil Oil Canada, Ltd.

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# APPENDIX 1

TABLE A.1

Start-End dates for the Drifters

| ID Number | Year | Start | End |
|---|---|---|---|
| 177 | 1976 | 95 (April 5) | 156 (June 4) |
| 1115 | 1977 | 312 (November 8) | 344 (December 10) |
| 1440 | 1977 | 339 (December 5) | 381 (January 16) |
| 46 | 1977 | 354 (December 20) | 367 (January 2) |
| 525 | 1977 | 356 (December 22) | 360 (December 26) |
| 647 | 1977 | 104 (April 14) | 112 (April 22) |
| 1224 | 1978 | 91 (April 1) | 122 (May 2) |
| 624 | 1978 | 95 (April 5) | 117 (April 27) |
| 731 | 1978 | 103 (April 13) | 178 (June 27) |
| 2600 | 1979 | 132 (May 12) | 191 (July 10) |
| 2601 | 1979 | 155 (June 4) | 201 (July 20) |
| 2602 | 1979 | 95 (April 5) | 200 (July 19) |
| 2604 | 1979 | 155 (June 4) | 200 (July 19) |
| 2605 | 1979 | 61 (March 2) | 200 (July 19) |
| 2610 | 1980 | 63 (March 3) | 152 (May 31) |
| 2613 | 1980 | 150 (May 29) | 241 (August 28) |
| 2630 | 1980 | 89 (March 29) | 199 (July 17) |
| 2632 | 1980 | 89 (March 29) | 332 (November 27) |
| 2633 | 1980 | 171 (June 19) | 327 (November 22) |
| 2634 | 1980 | 121 (April 30) | 328 (November 23) |
| 2636 | 1980 | 150 (May 29) | 185 (July 3) |
| 370 | 1980 | 48 (February 17) | 83 (March 23) |
| 2594 | 1981 | 118 (April 28) | 222 (August 10) |

TABLE A.1 (Cont'd)

| ID Number | Year | Start | End |
|---|---|---|---|
| 2596 | 1981 | 113 (April 23) | 328 (November 24) |
| 2631 | 1981 | 97 (April 7) | 129 (May 9) |
| 2637 | 1982 | 92 (April 2) | 145 (May 25) |
| 2638 | 1982 | 62 (March 3) | 104 (April 14) |
| 2639 | 1982 | 92 (April 2) | 118 (April 28) |
| 2641 | 1982 | 125 (May 5) | 172 (June 21) |

Position at 1200 GMT each day is shown as a square with every tenth square darkened.

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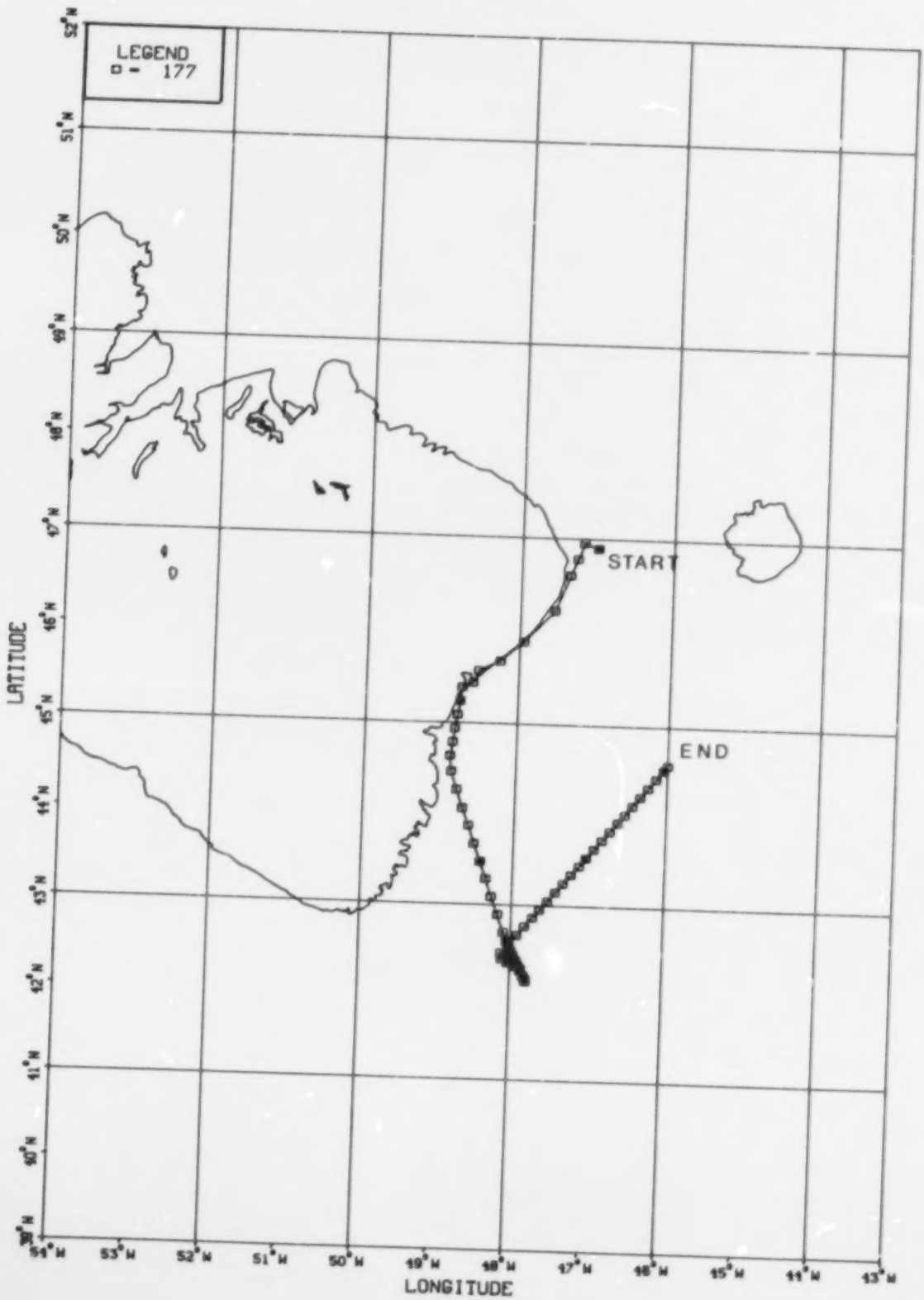
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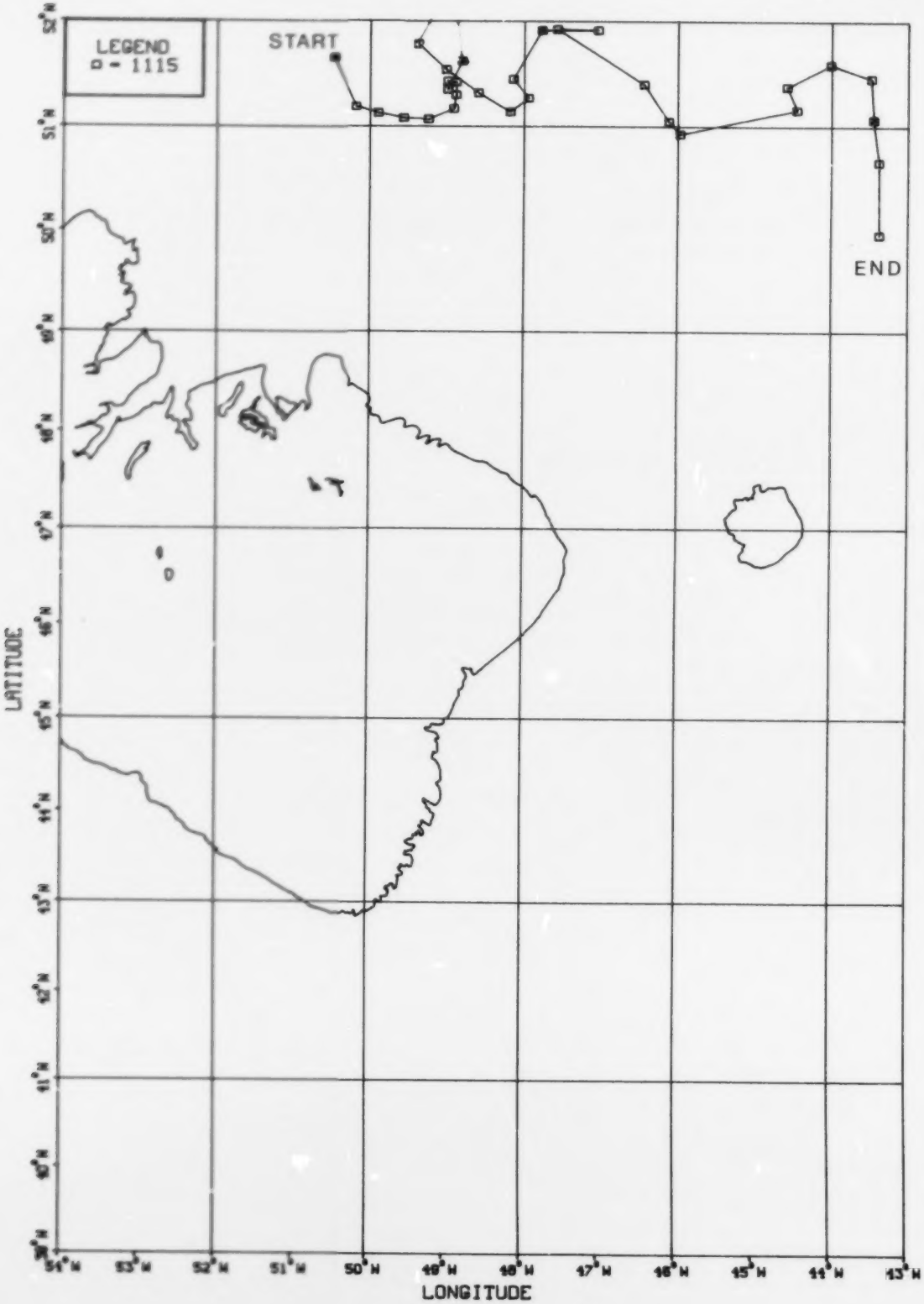
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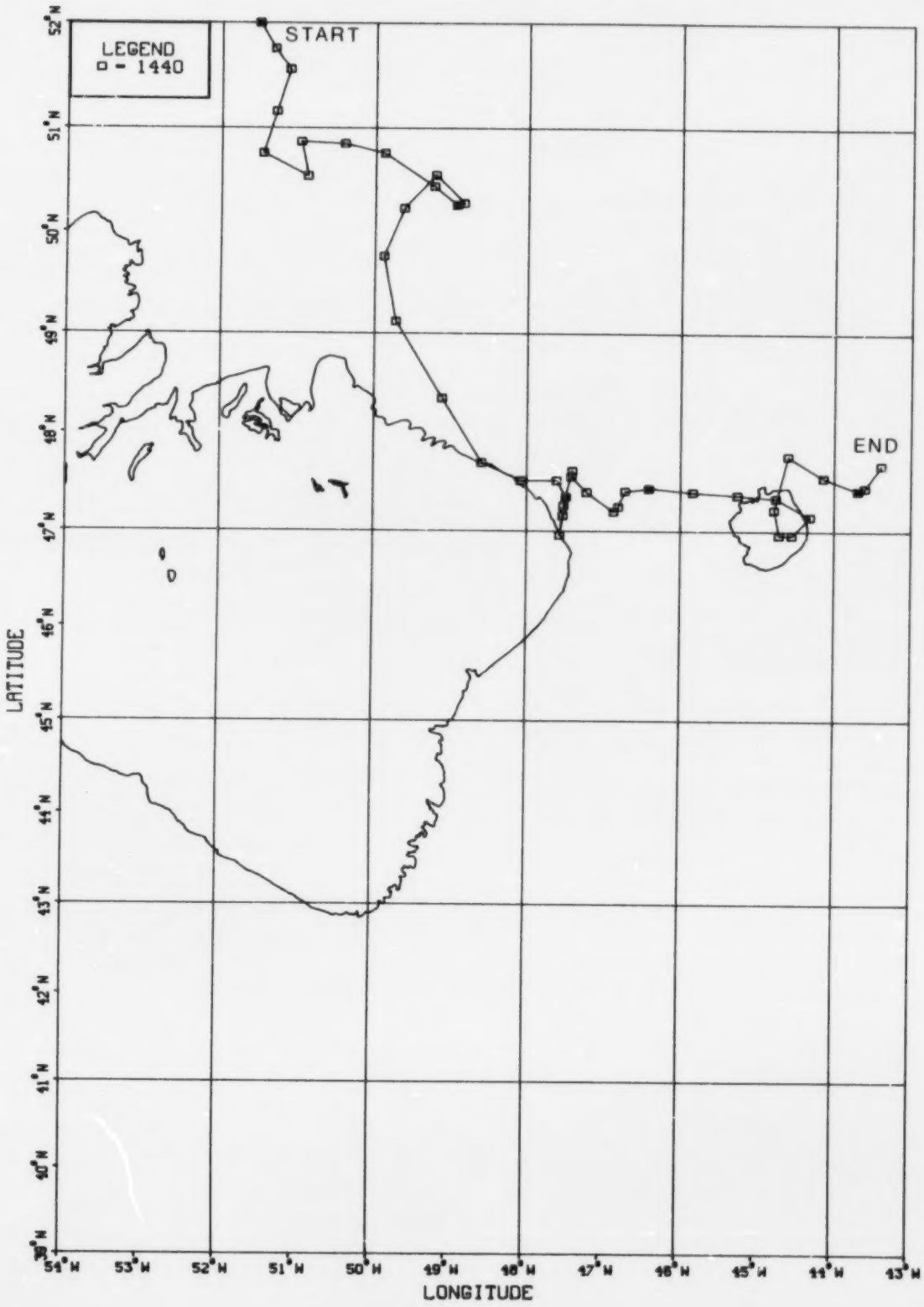
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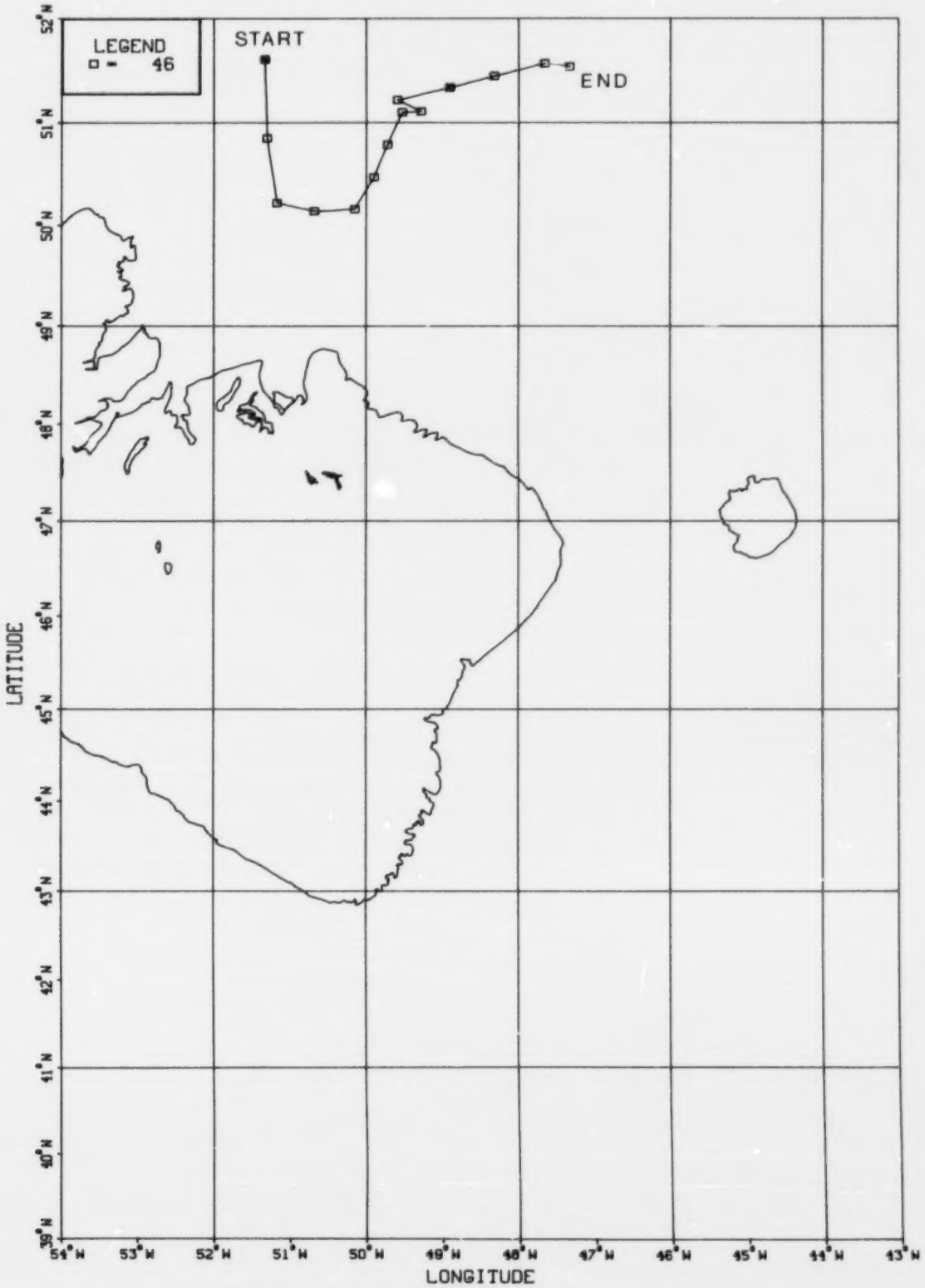
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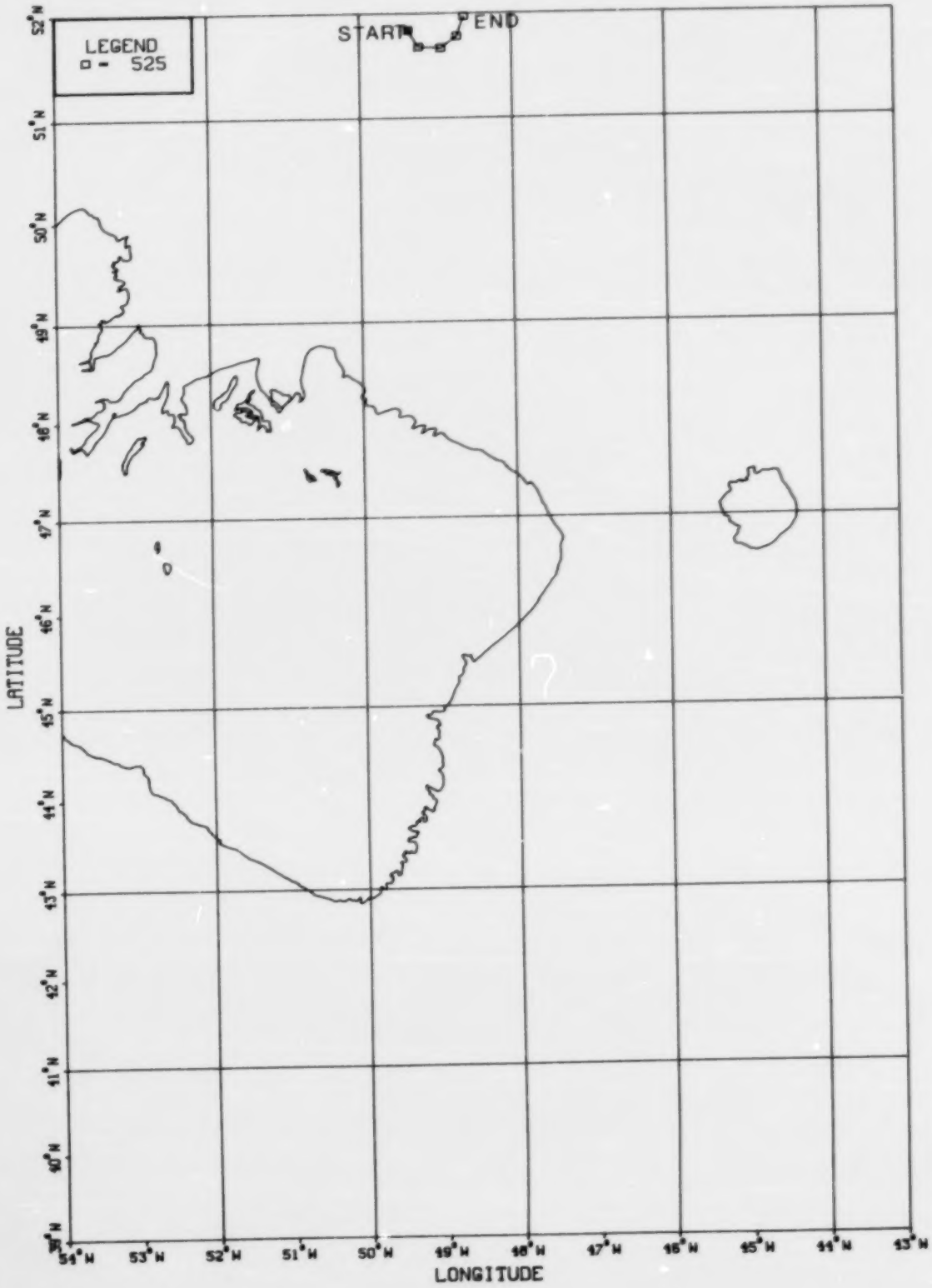
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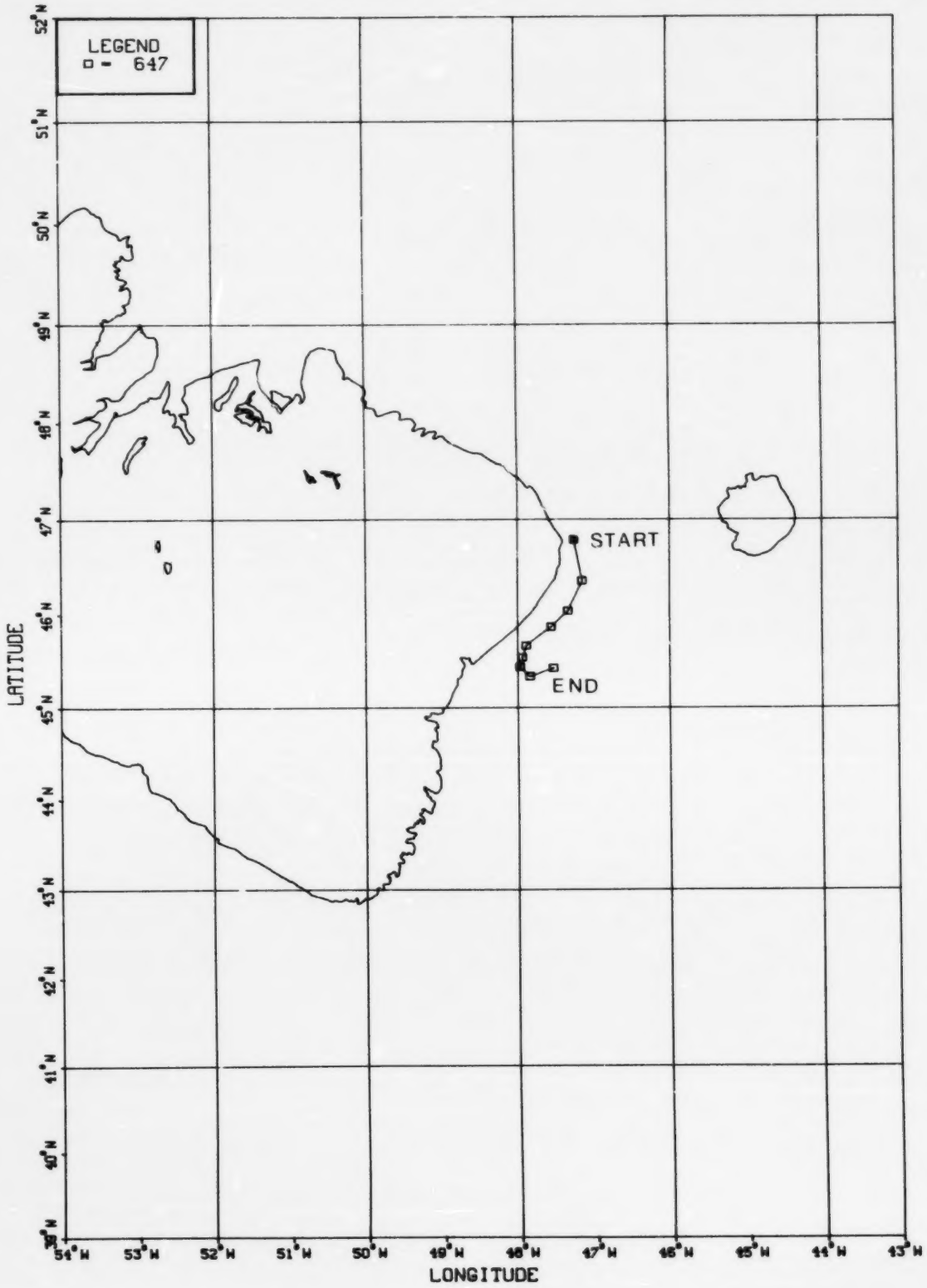
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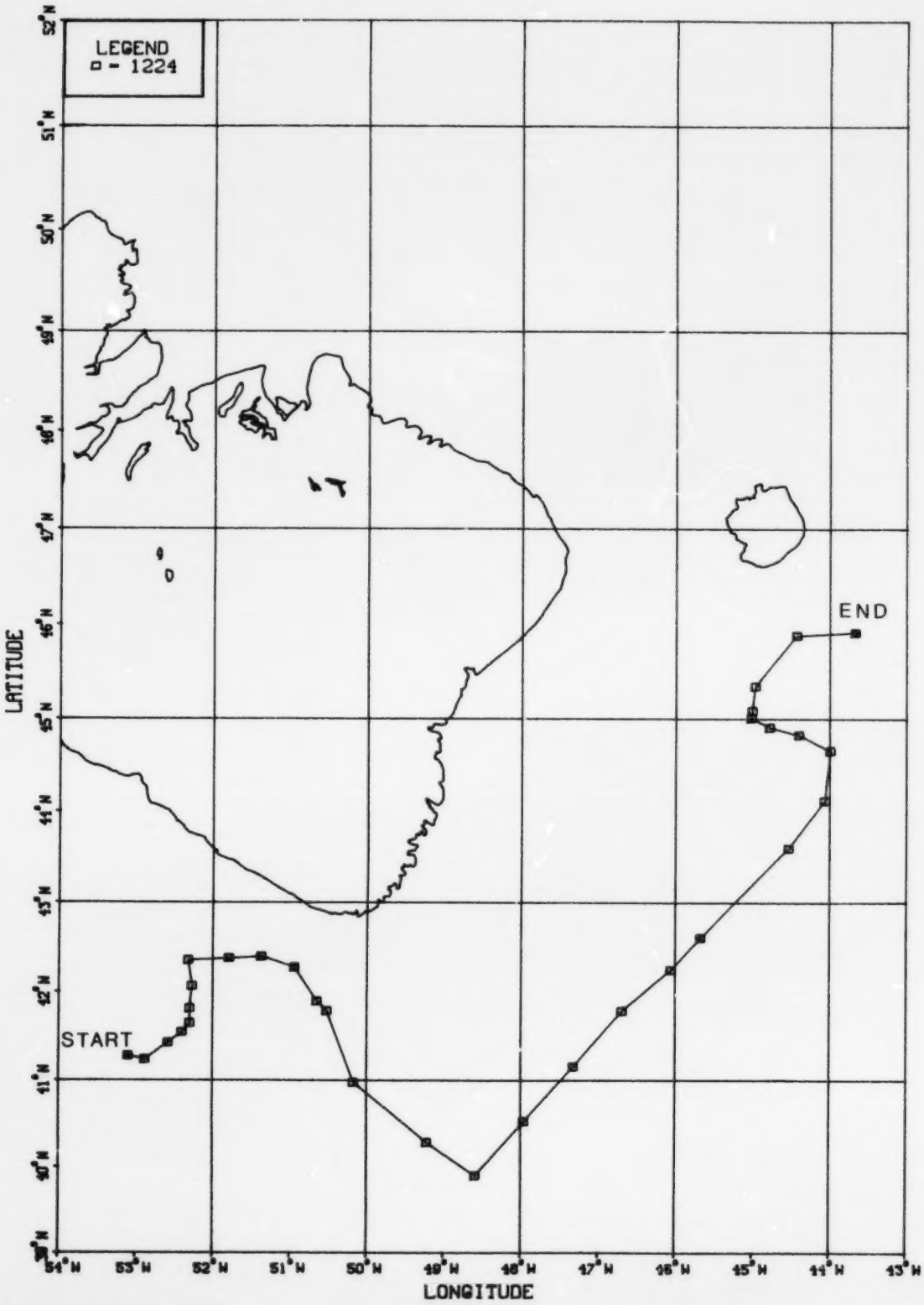
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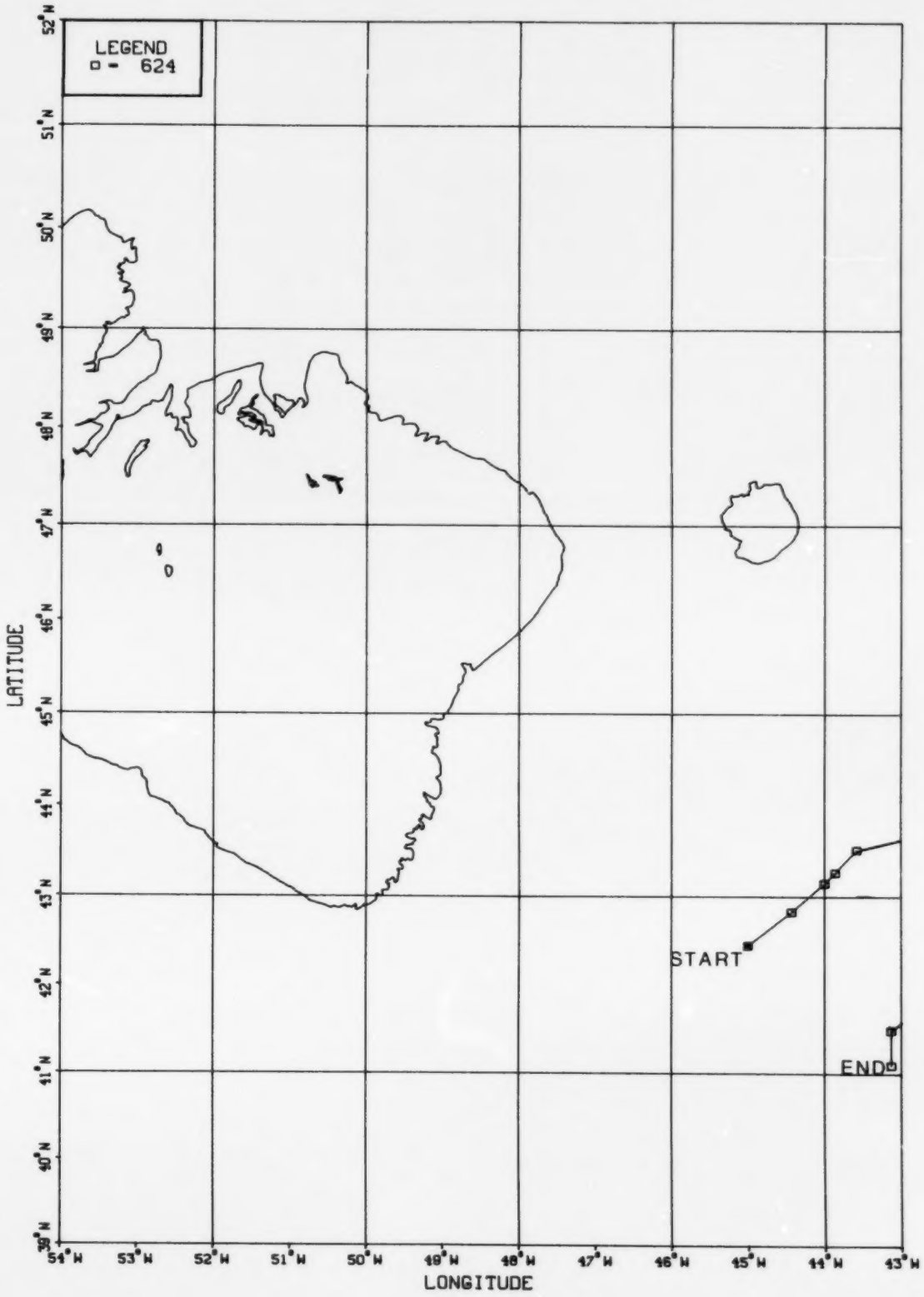
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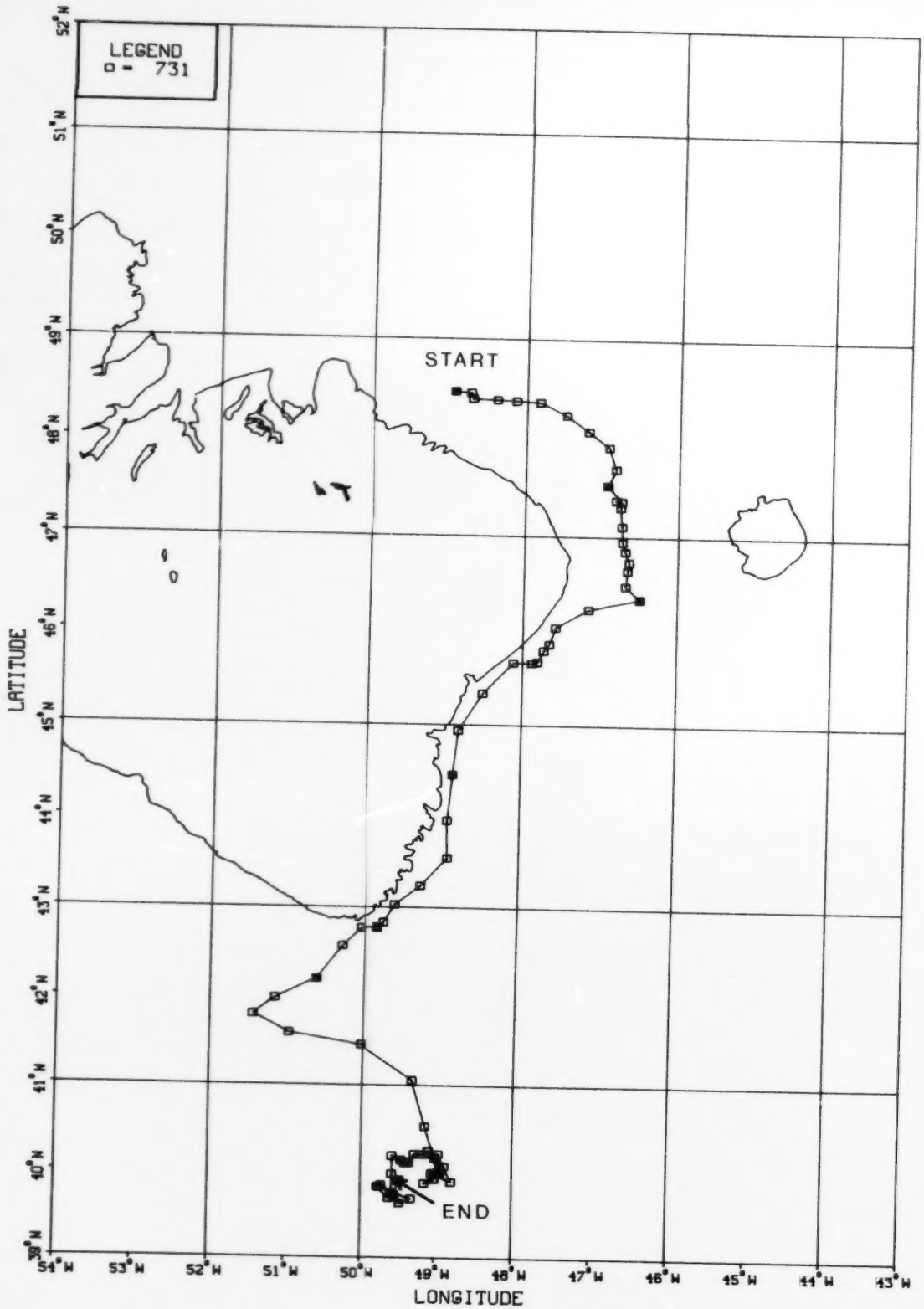
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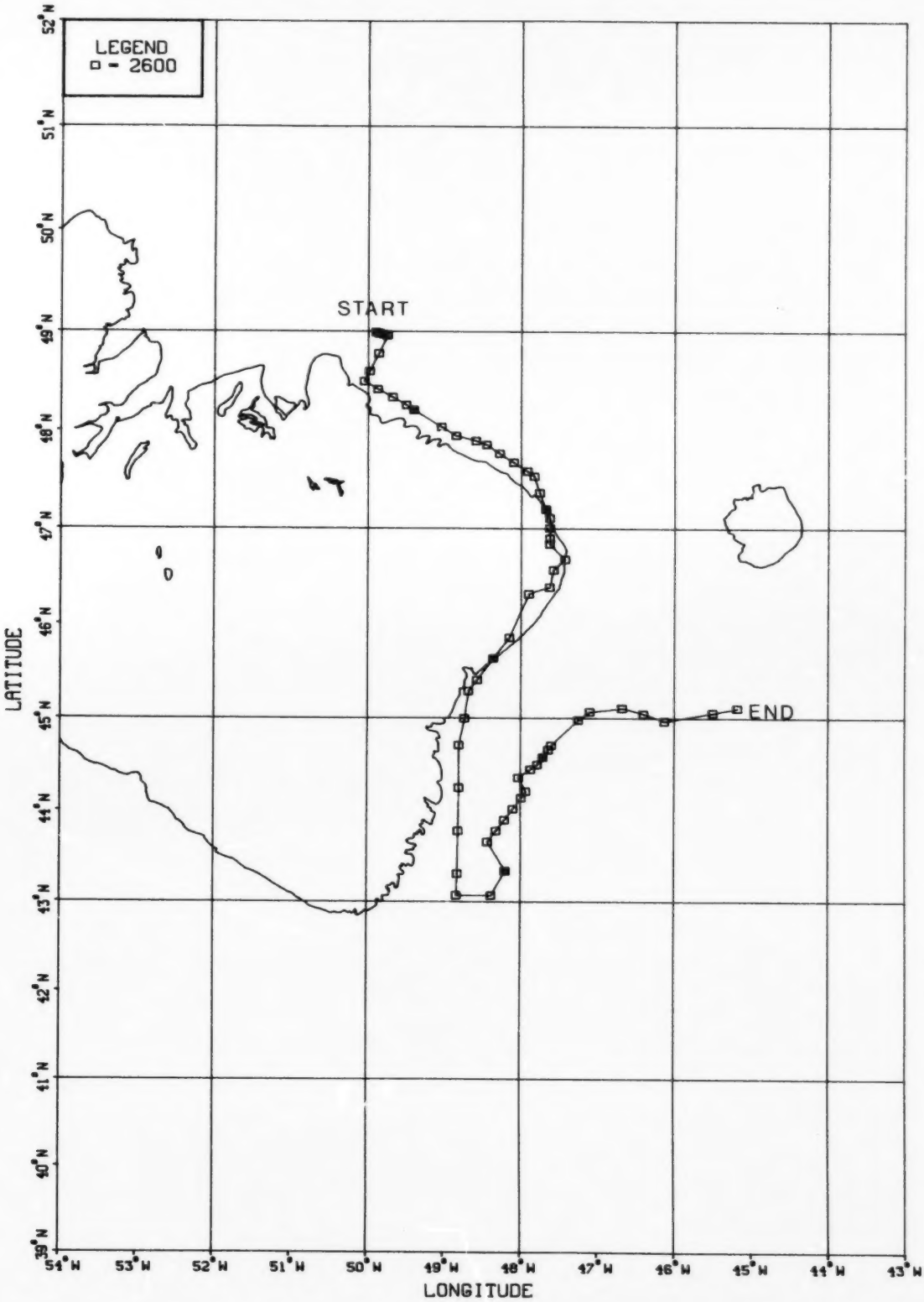
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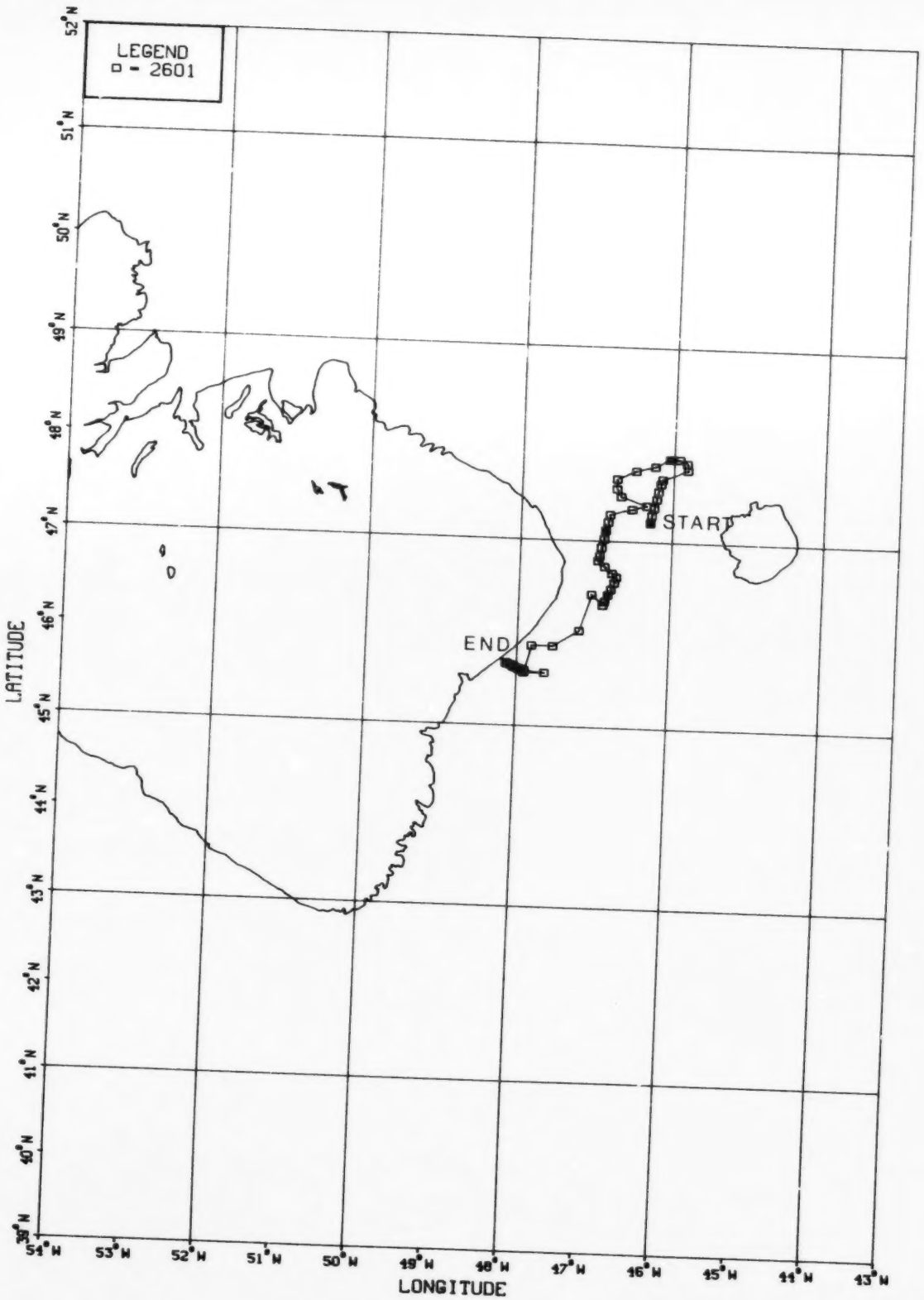
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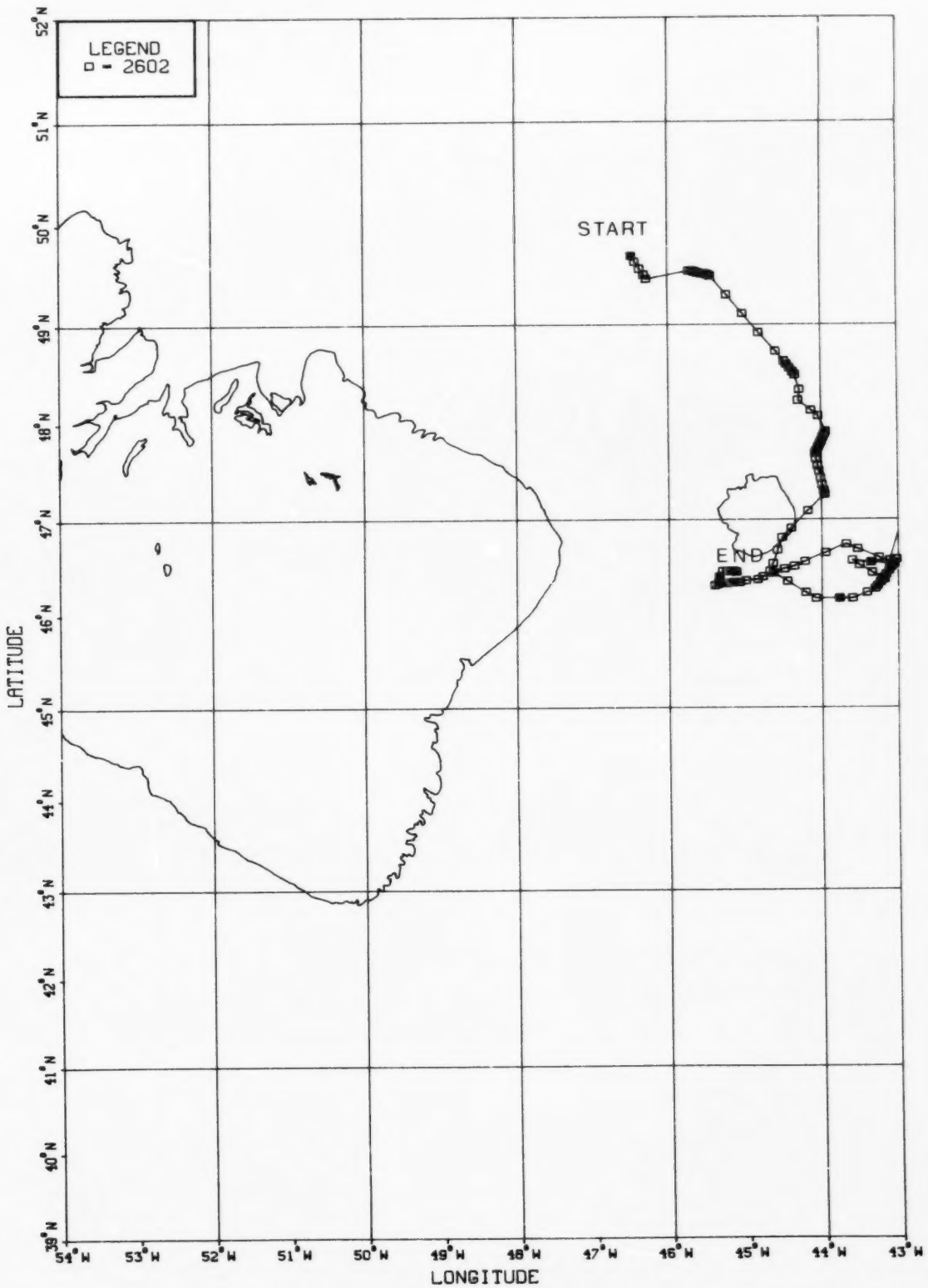
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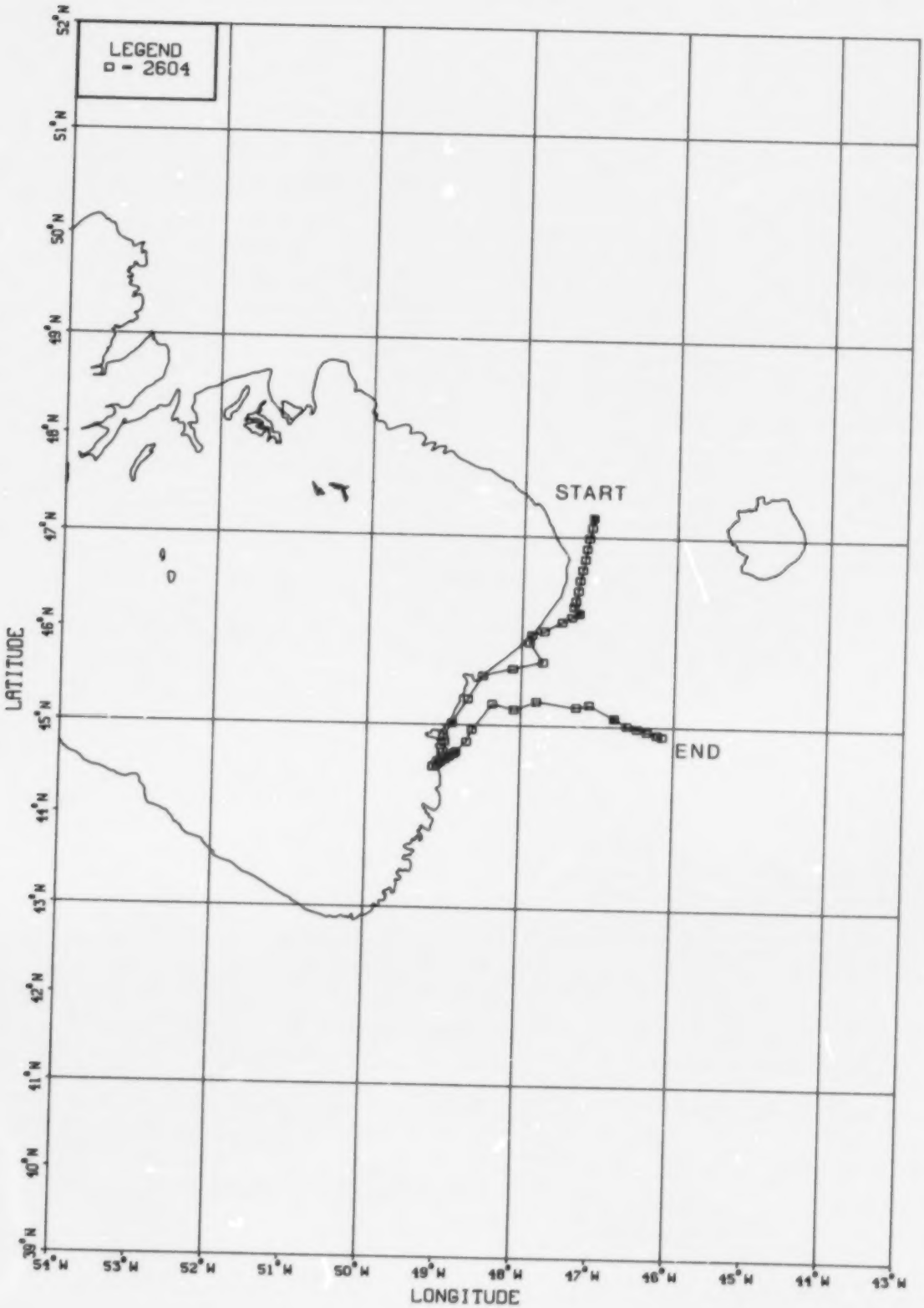
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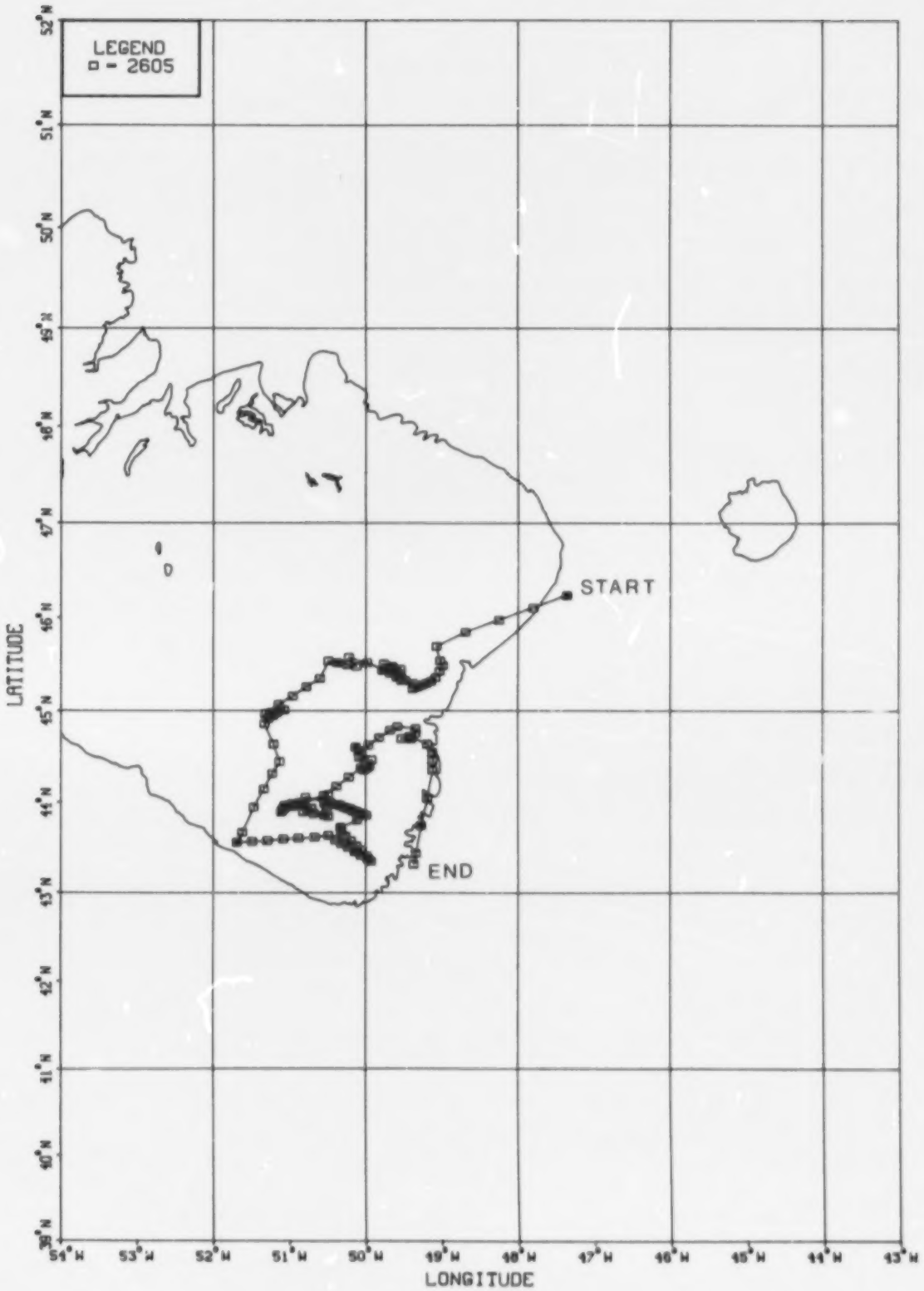
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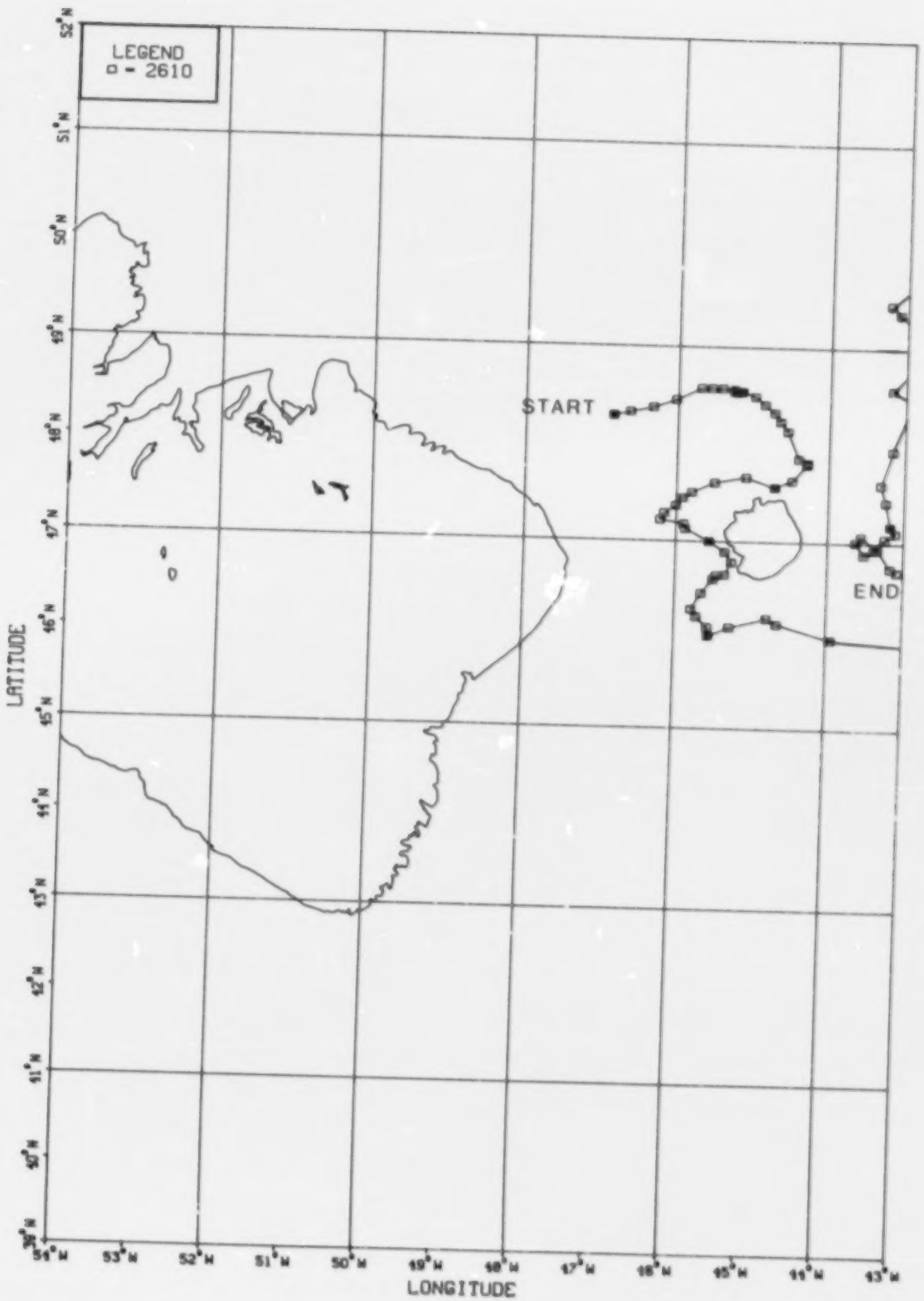
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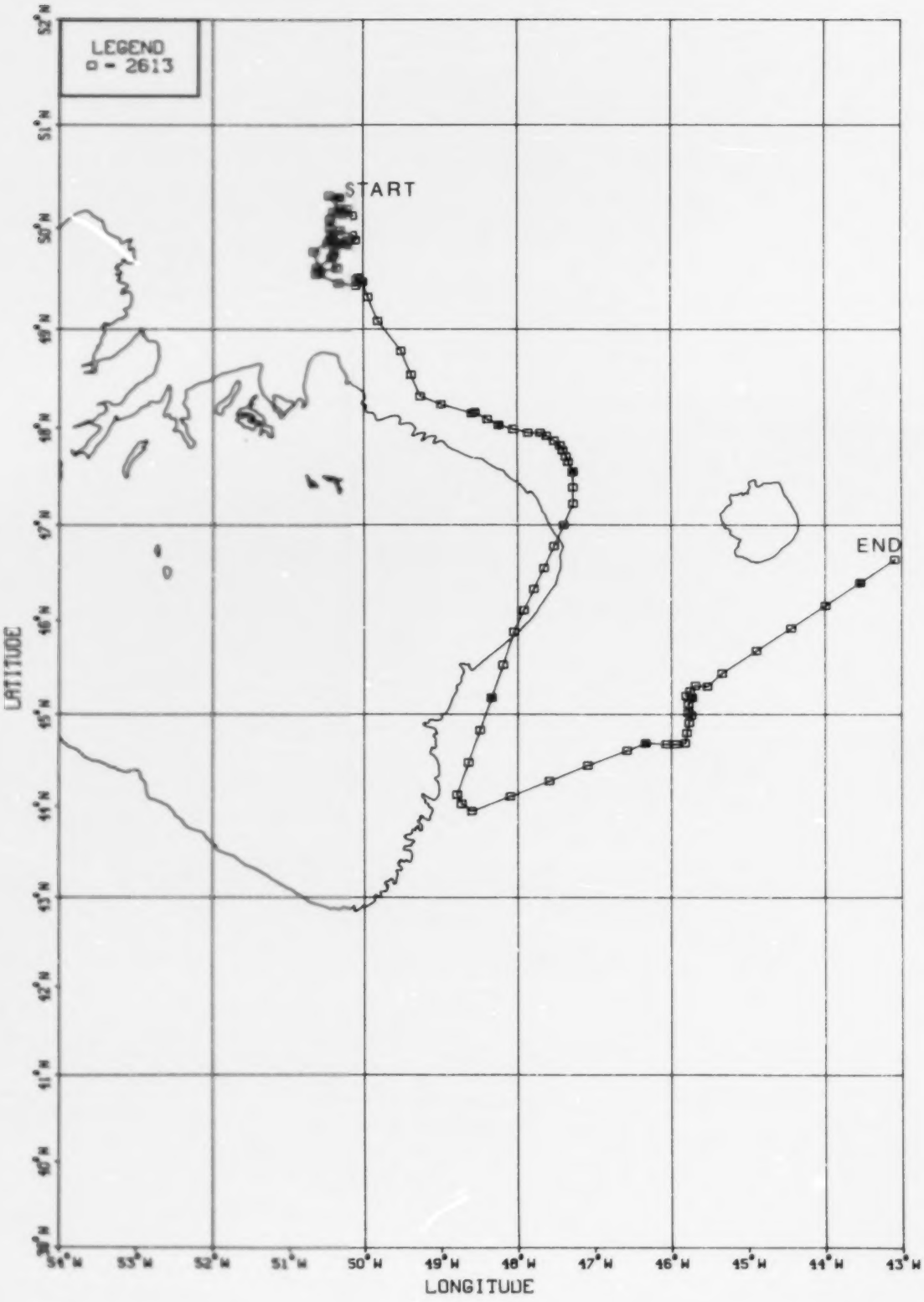
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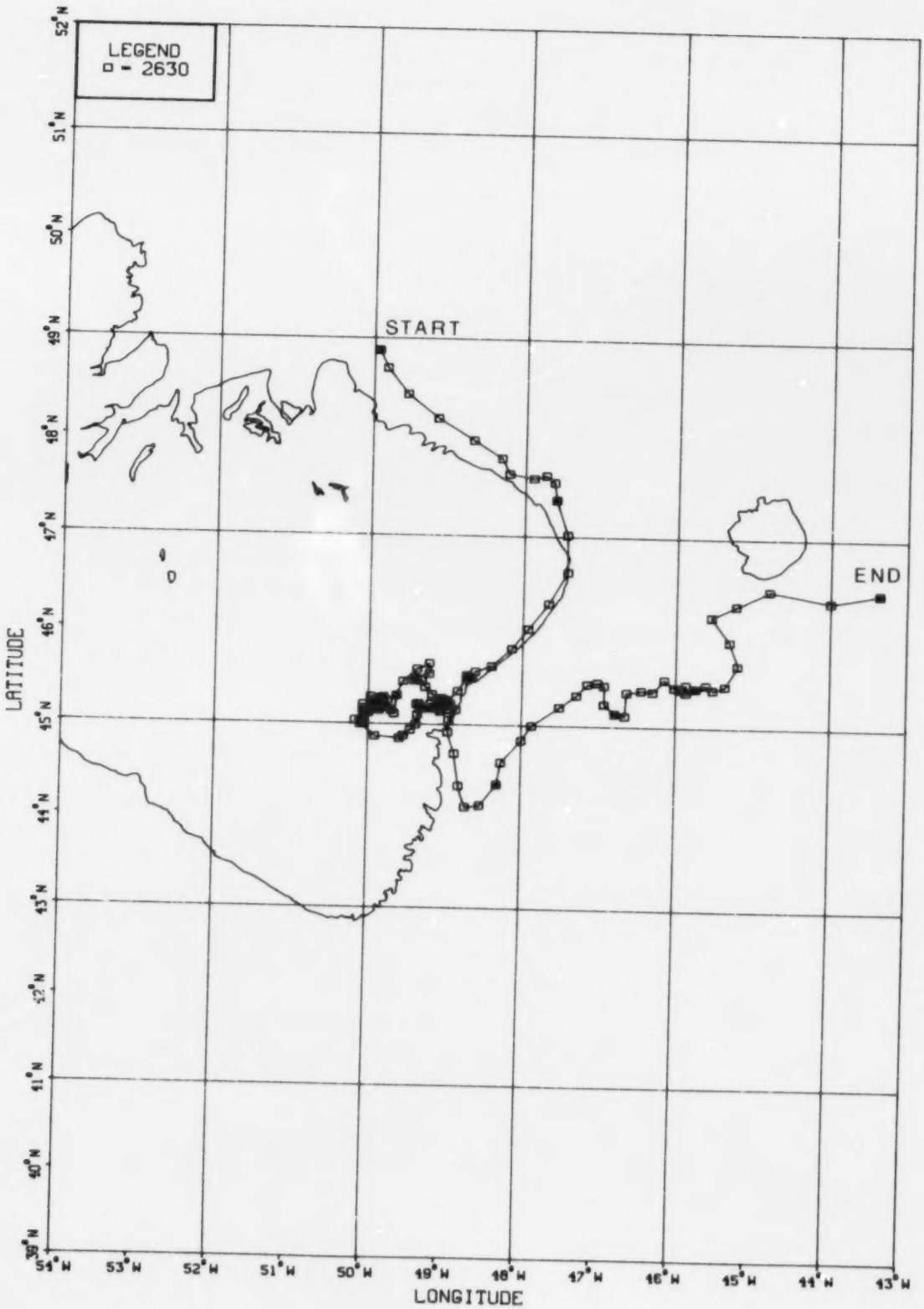
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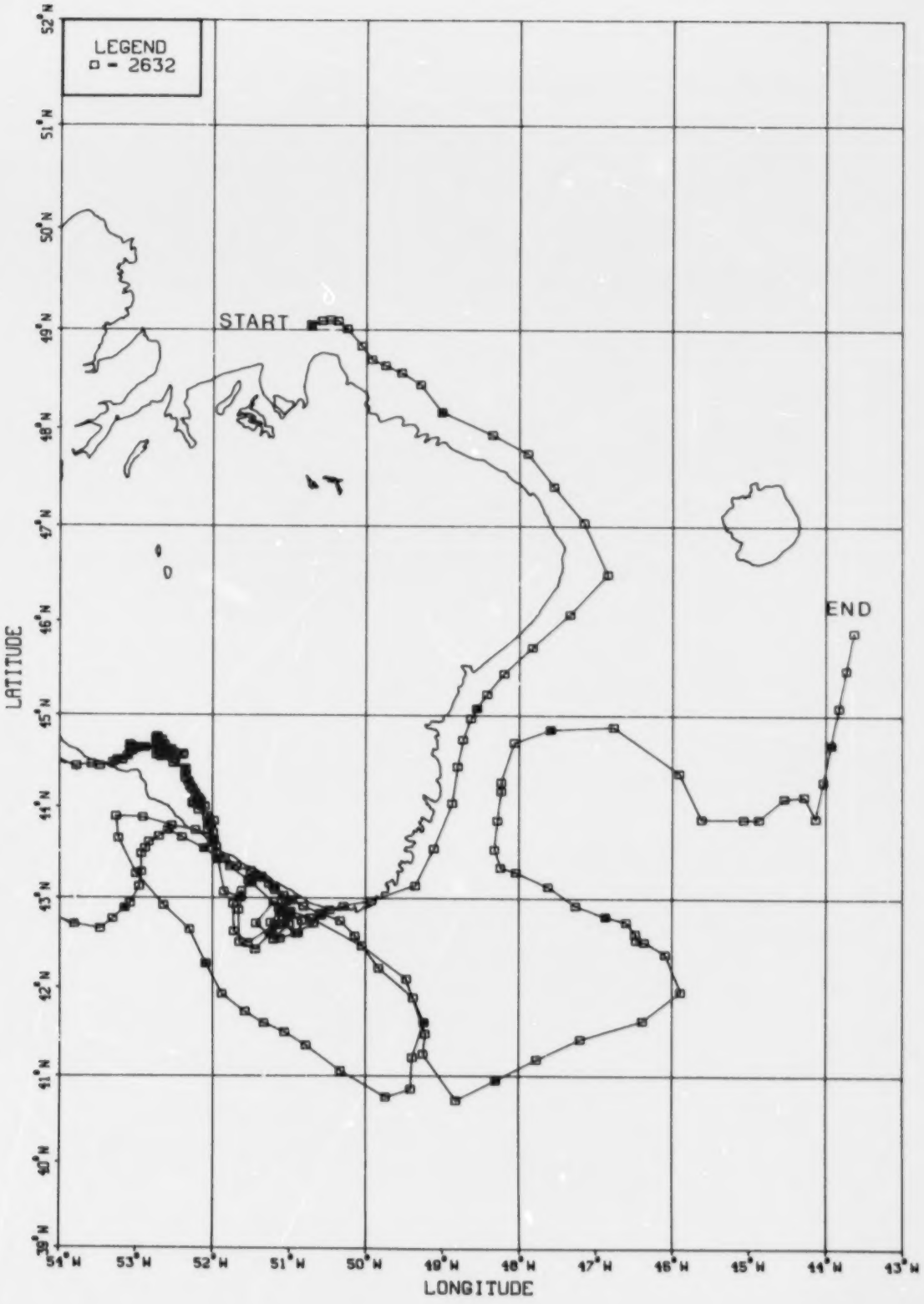
15°W
14°W
13°W

# BUOY TRACKS


LEGEND
□ - 2632
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
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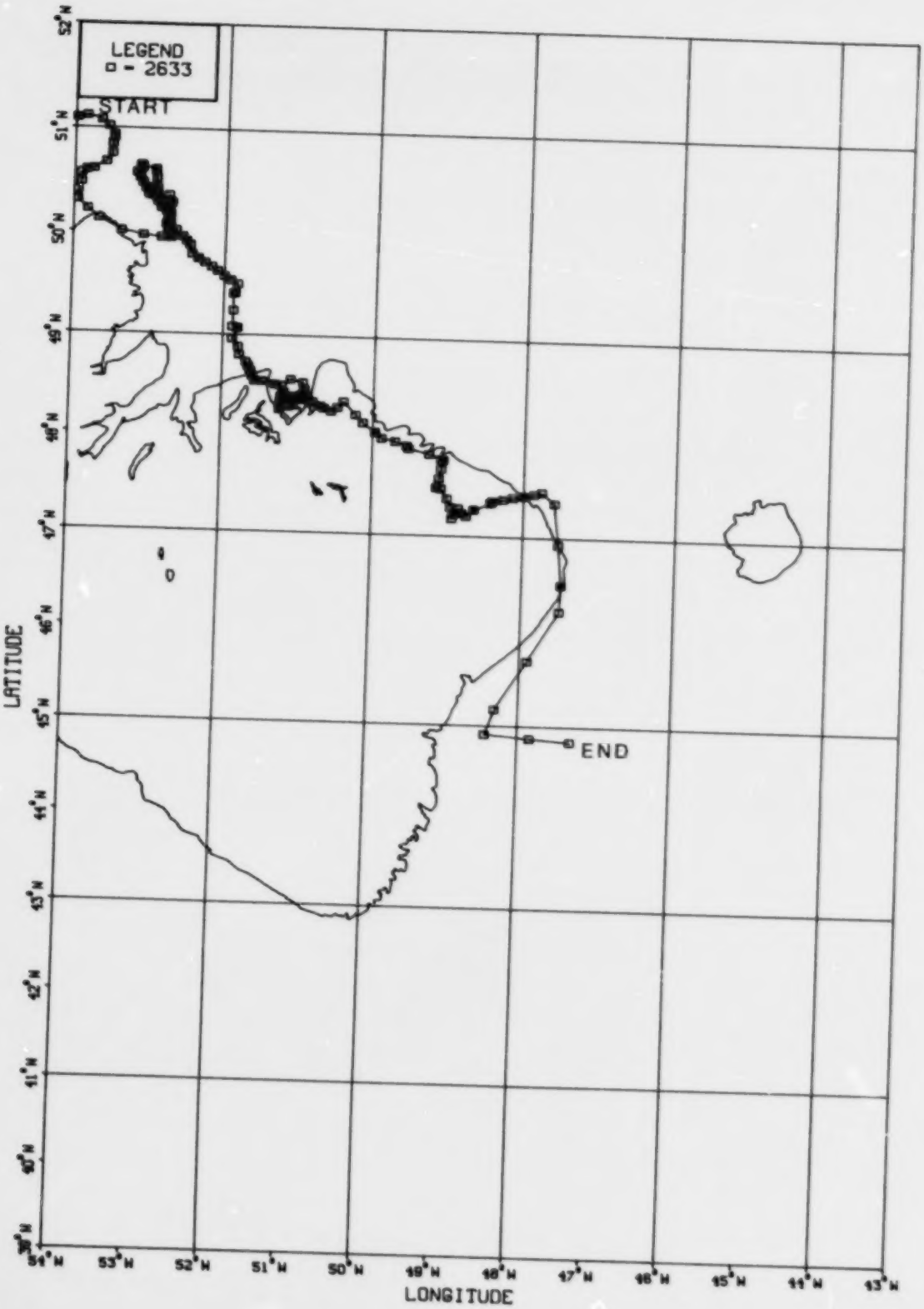
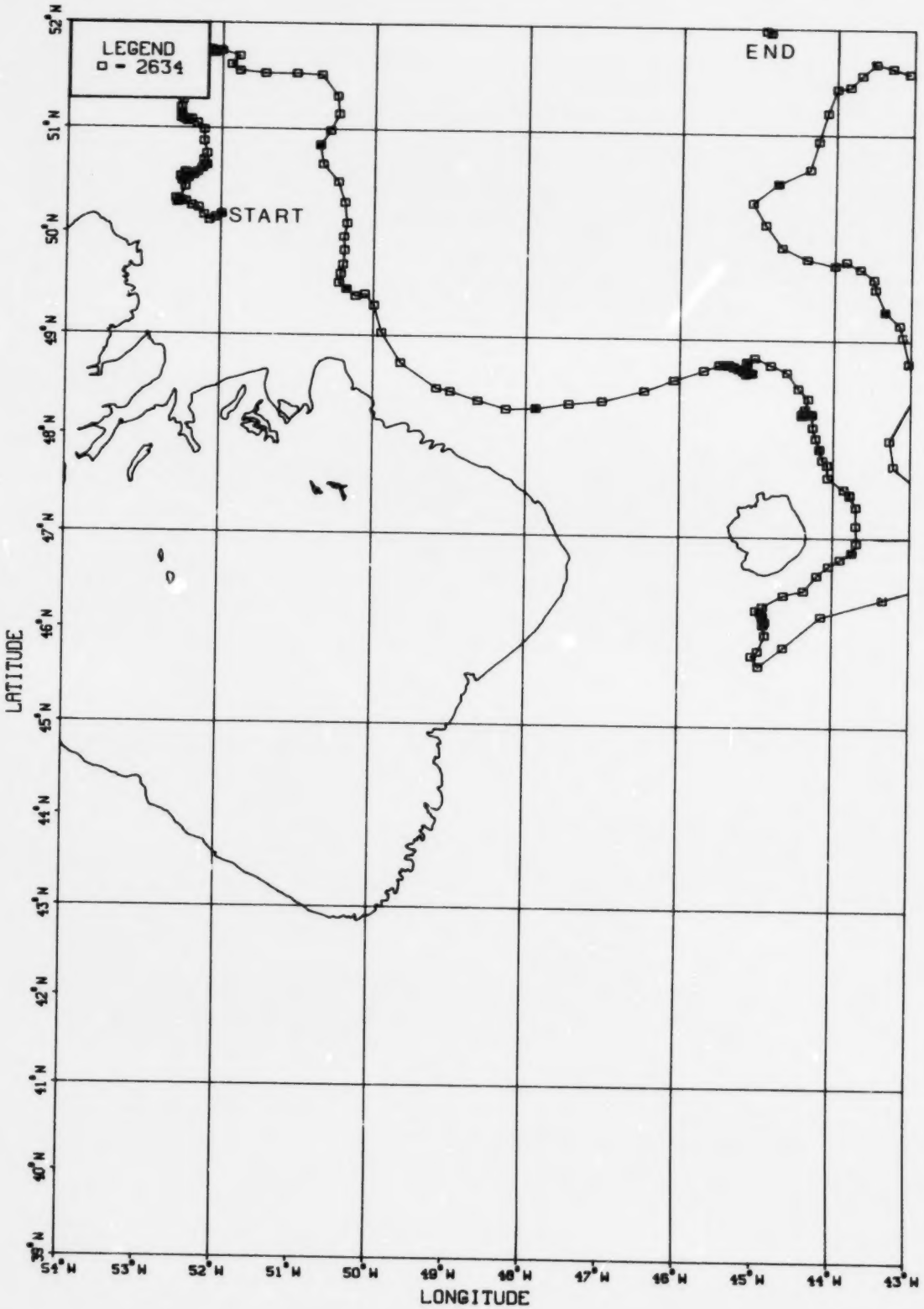
46°N
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2633
START
END
LATITUDE
LONGITUDE
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2634
START
END
LATITUDE
LONGITUDE
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51°N
50°N
49°N
48°N
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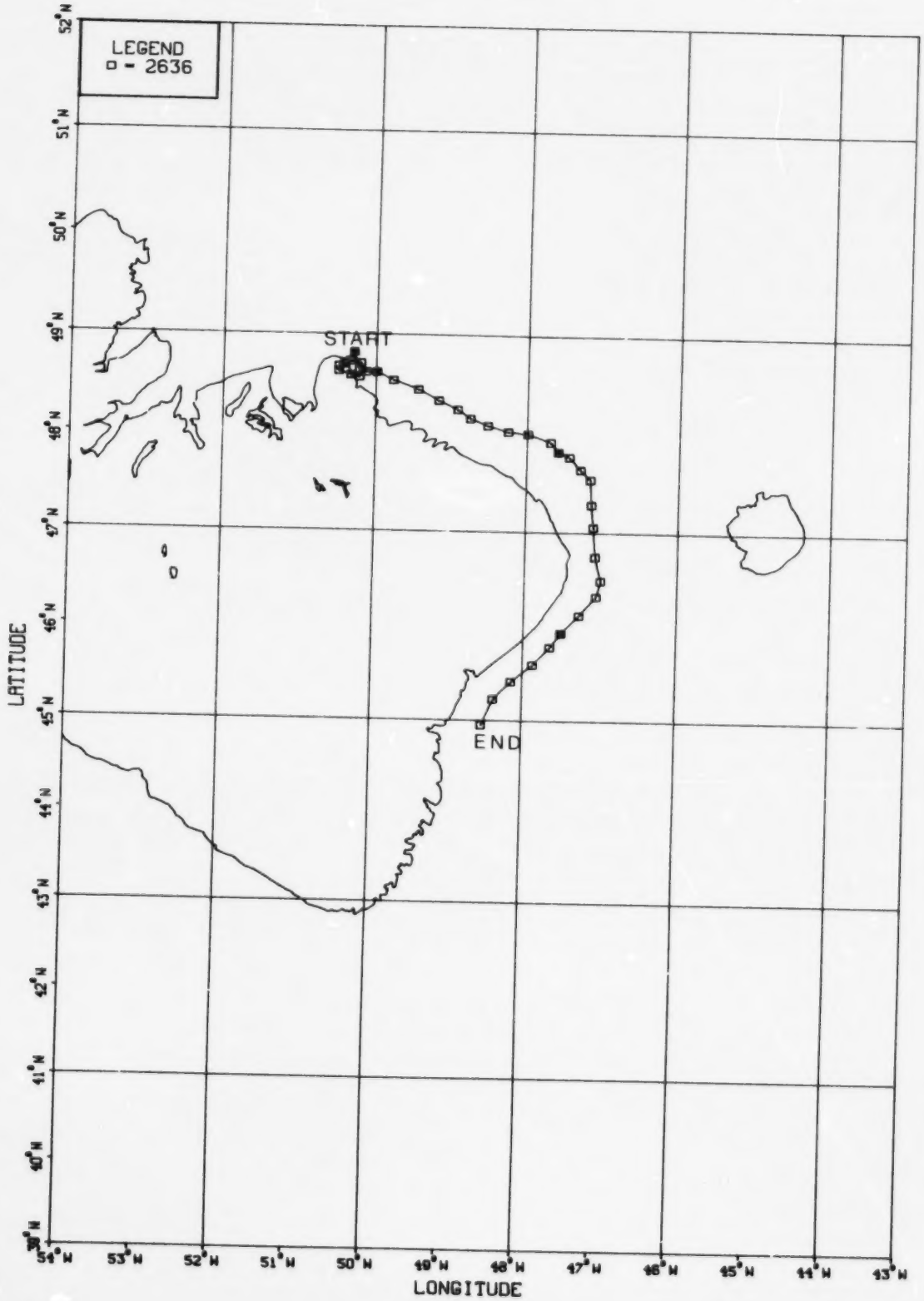
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2636
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
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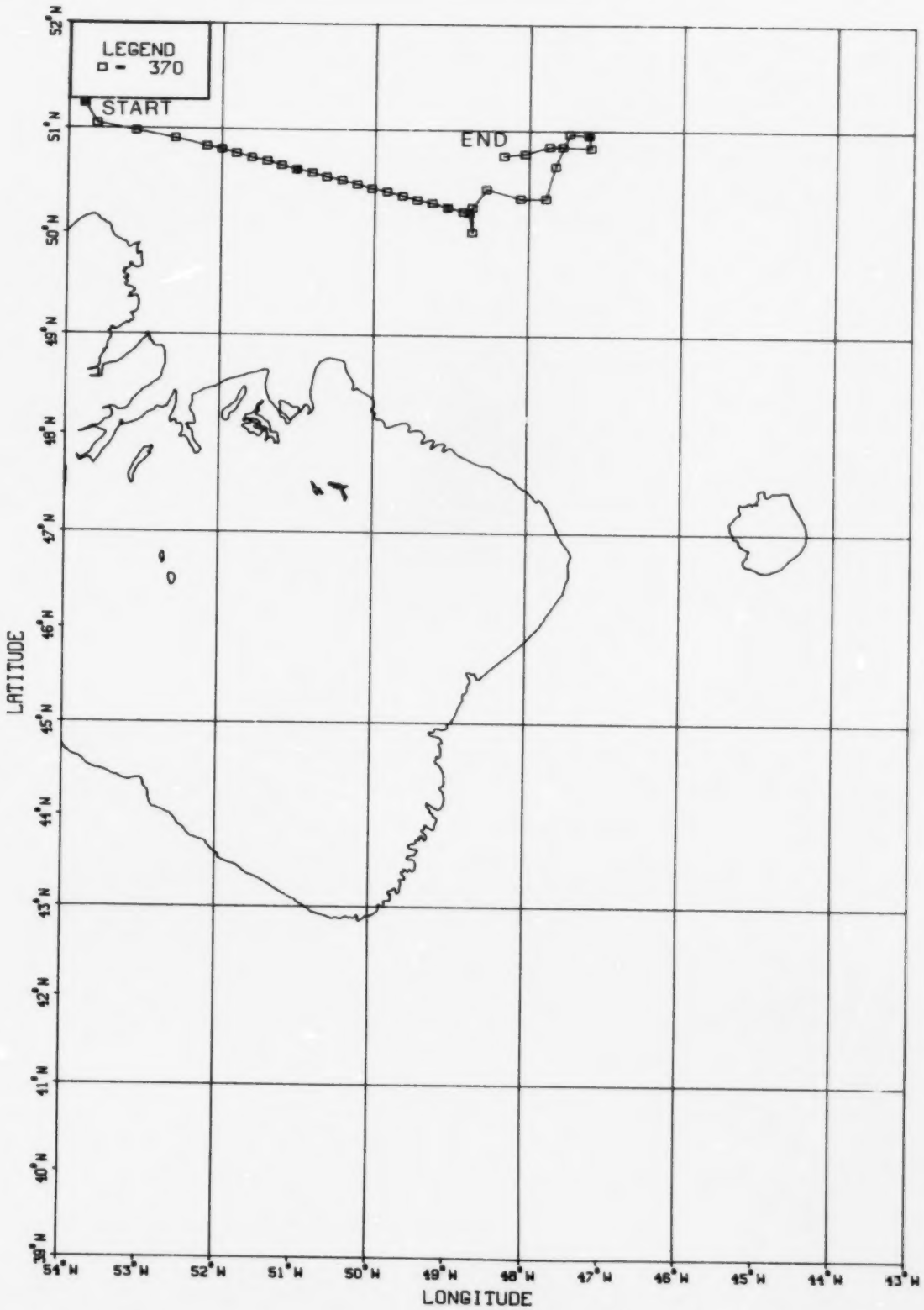
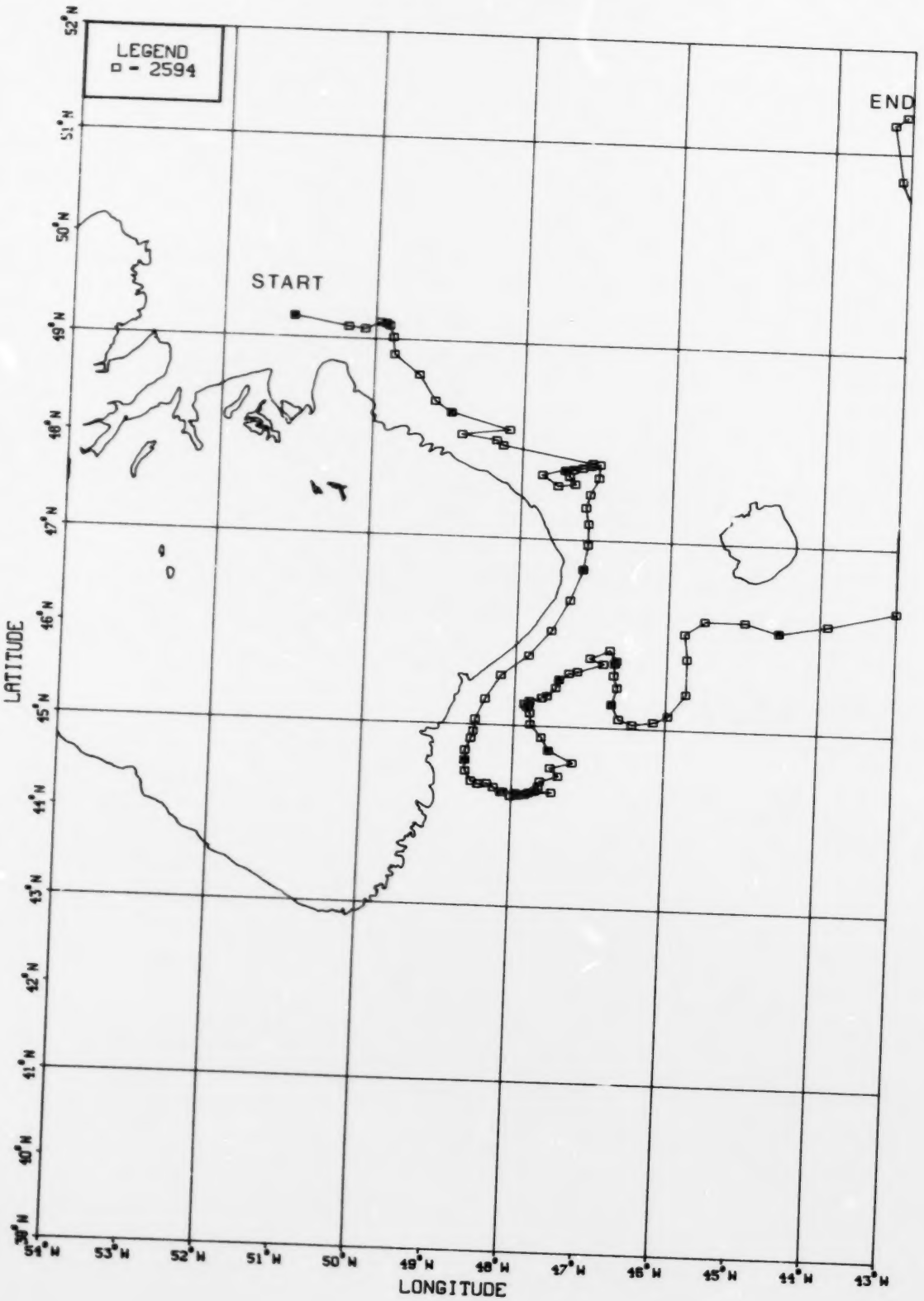
46°N
45°N
44°N
43°N
42°N
41°N
40°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

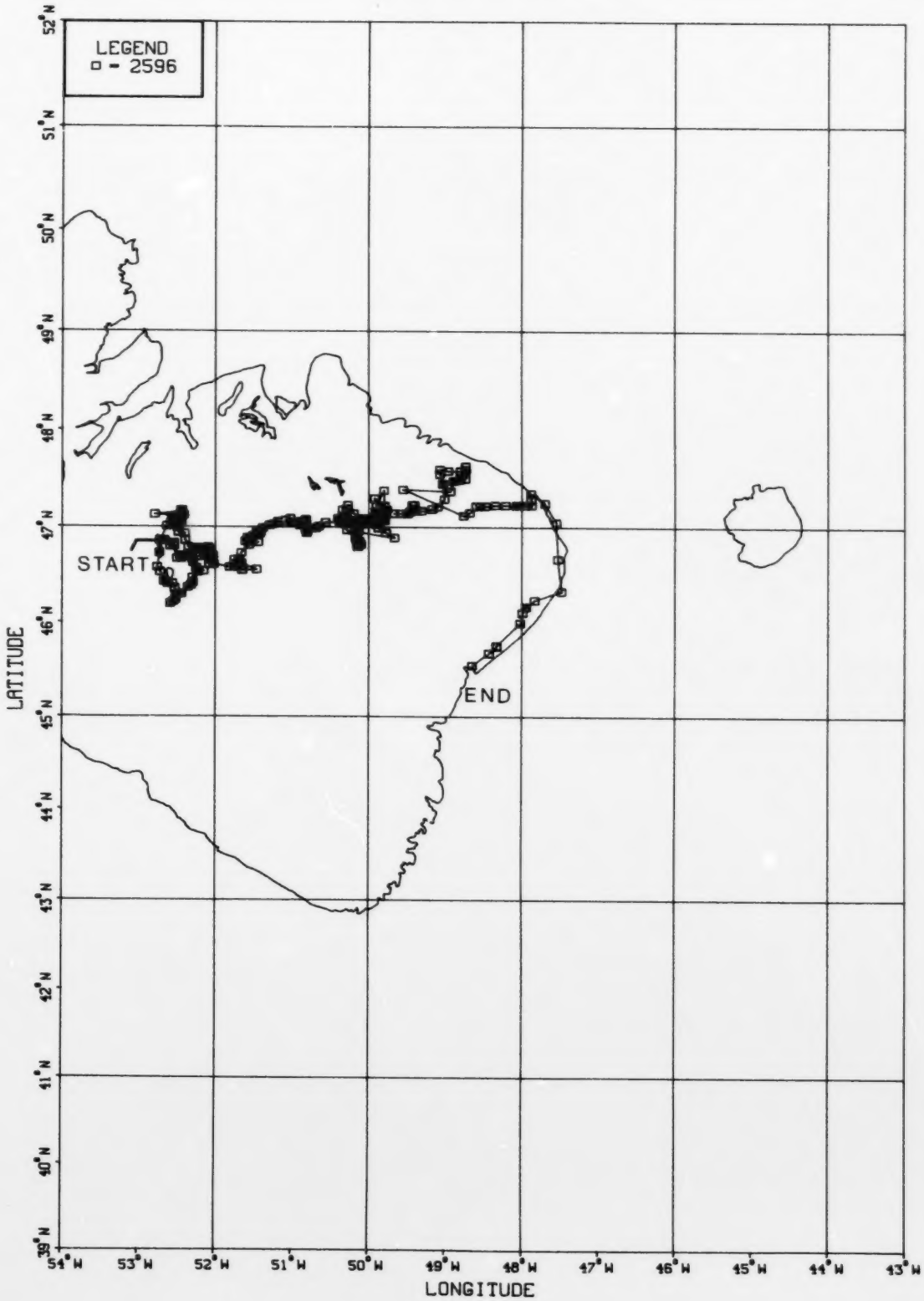
# BUOY TRACKS


LEGEND
□ - 370
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
47°N
46°N
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2594
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
47°N
46°N
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2596
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
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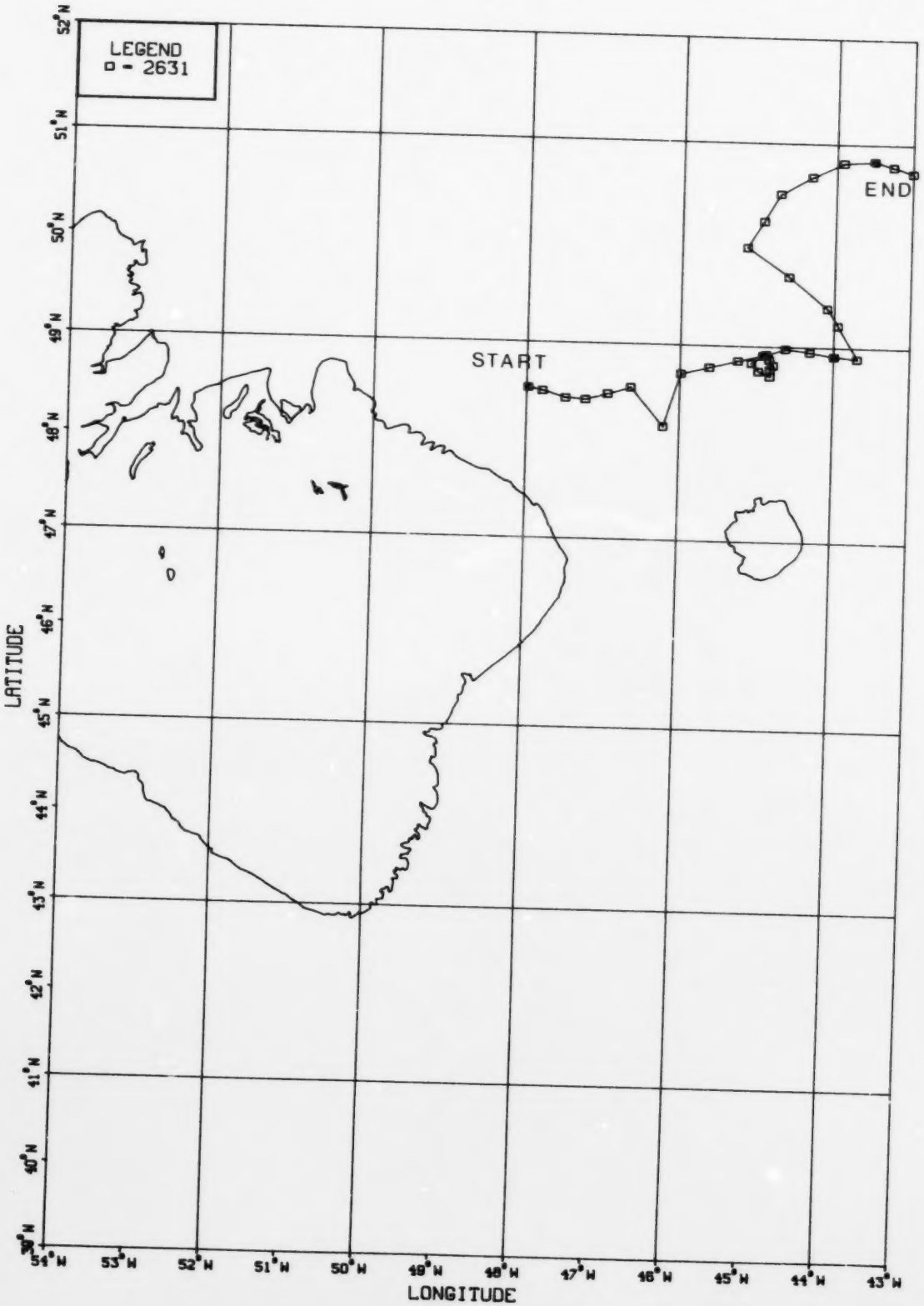
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2631
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
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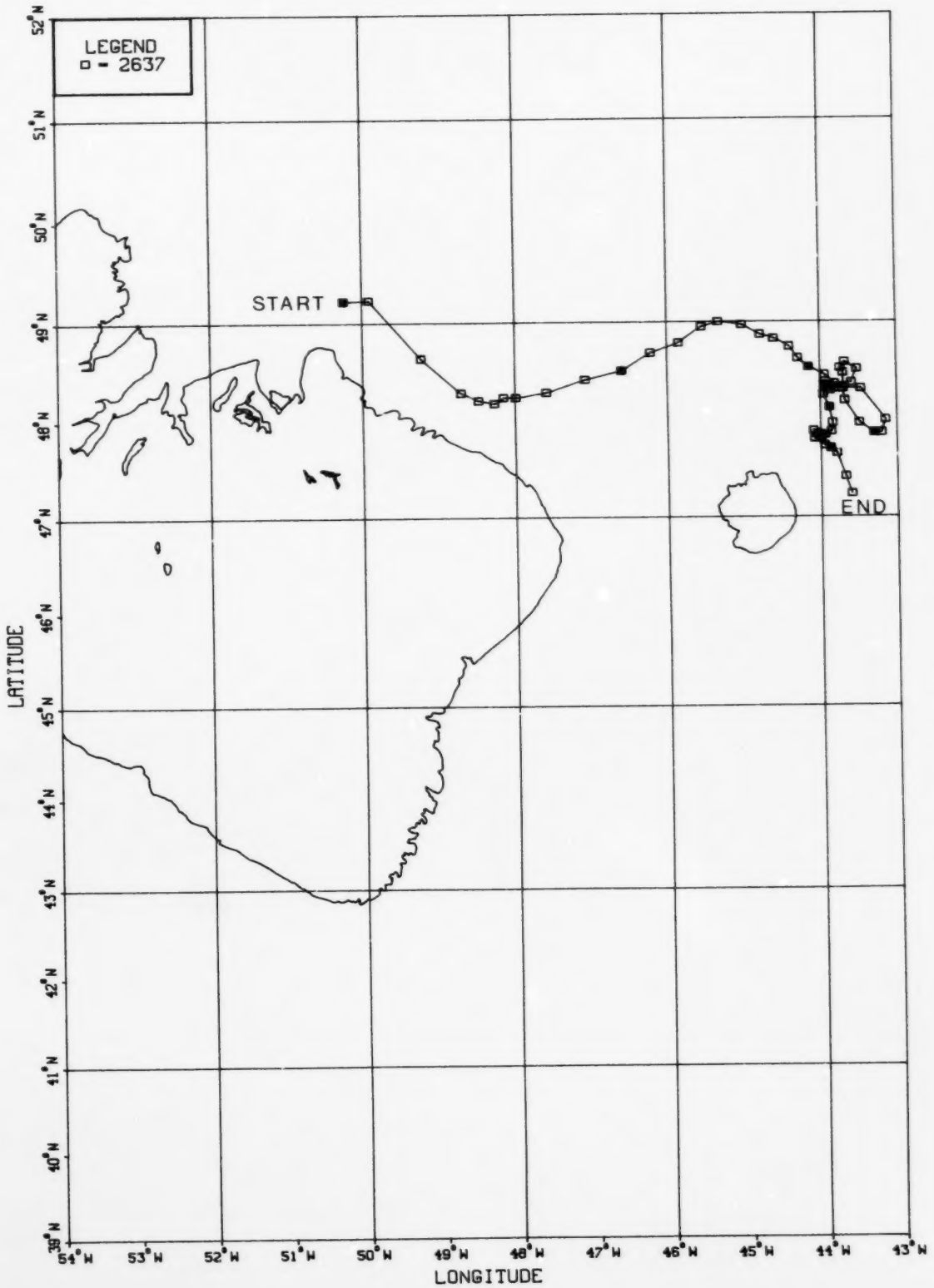
46°N
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2637
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
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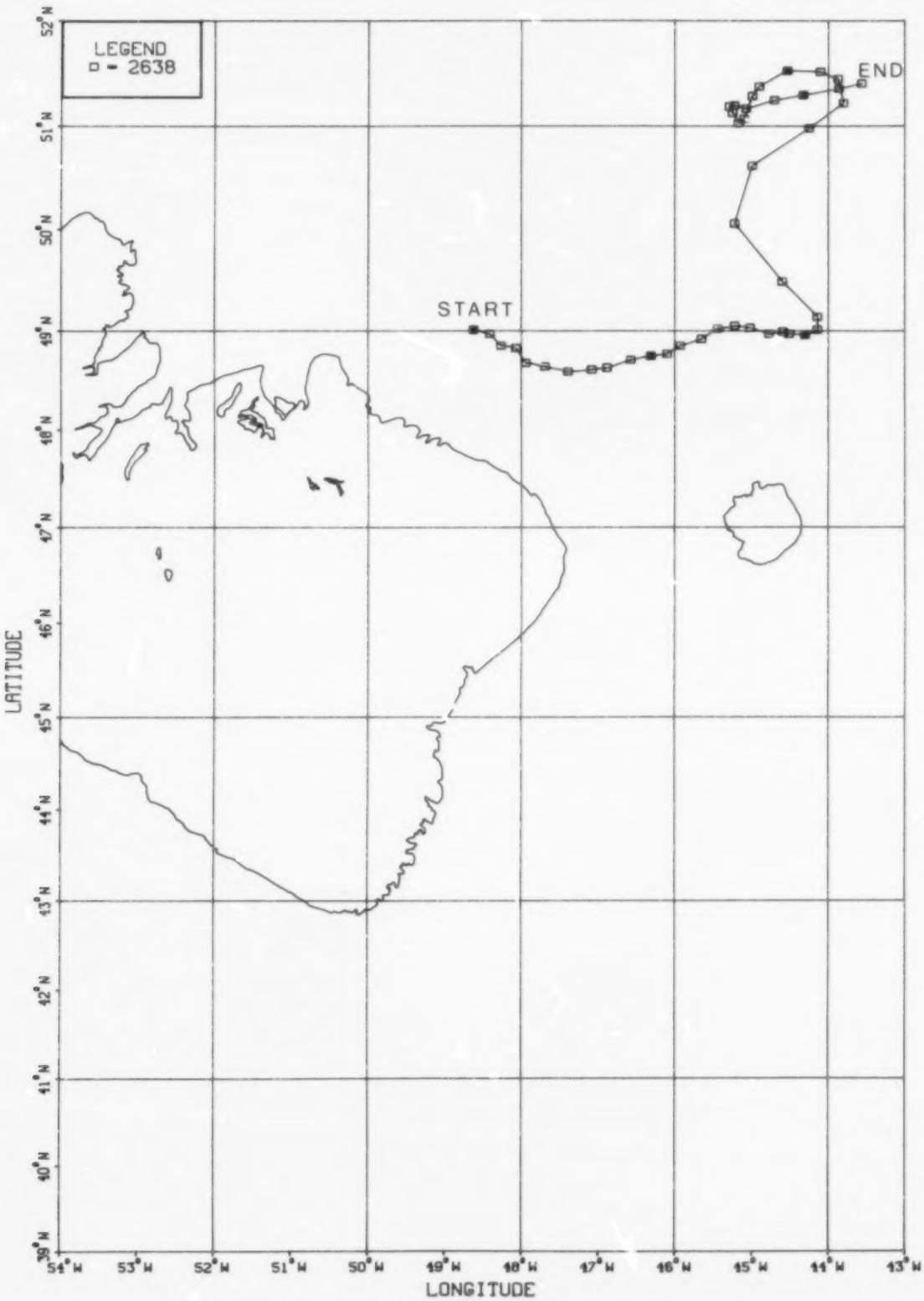
46°N
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

# BUOY TRACKS


LEGEND
□ - 2638
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
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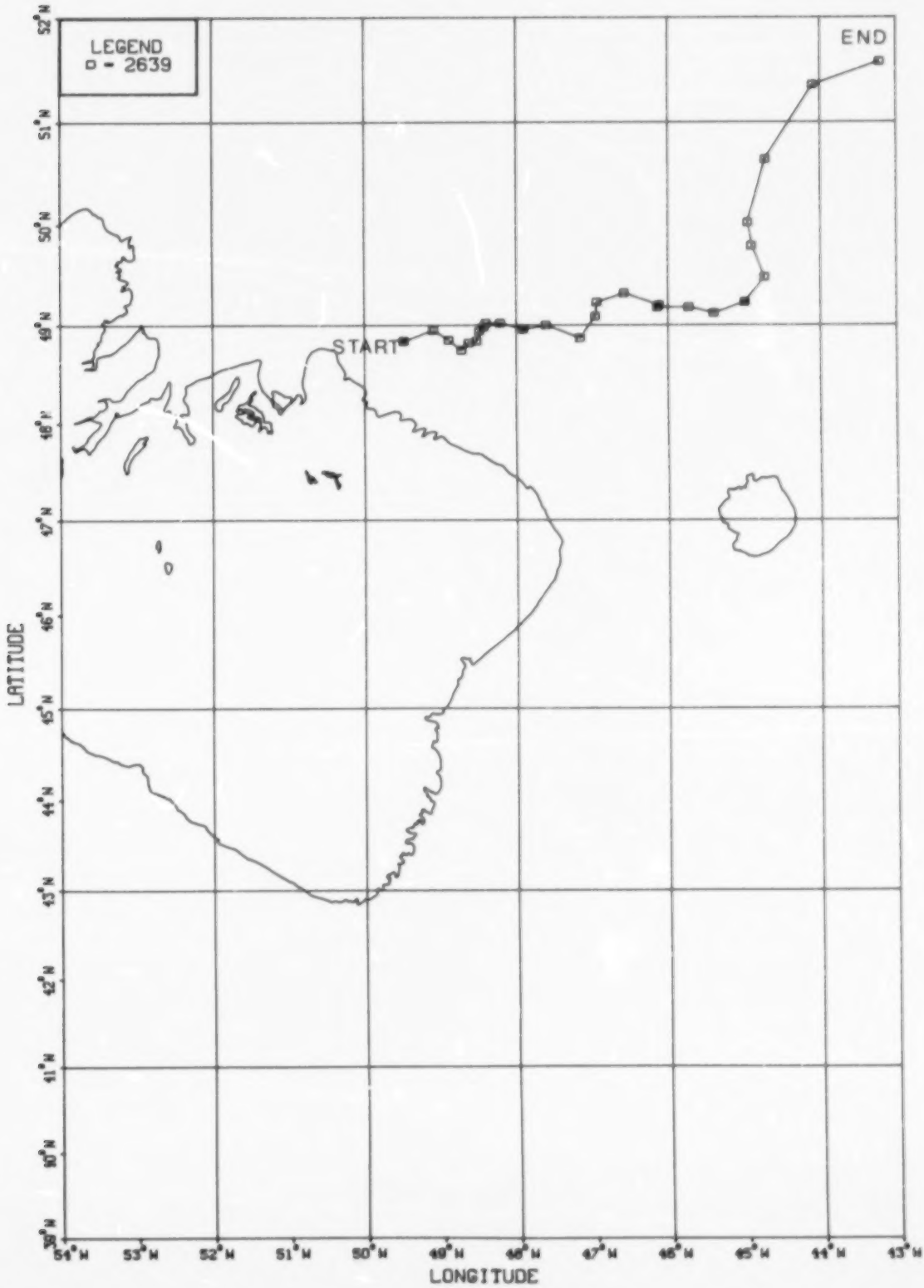
45°N
44°N
43°N
42°N
41°N
40°N
39°N
54°W
53°W
52°W
51°W
50°W
19°W
18°W
17°W
16°W
15°W
14°W
13°W

# BUOY TRACKS


LEGEND
□ - 2639
START
END
LATITUDE
LONGITUDE
54°W
53°W
52°W
51°W
50°W
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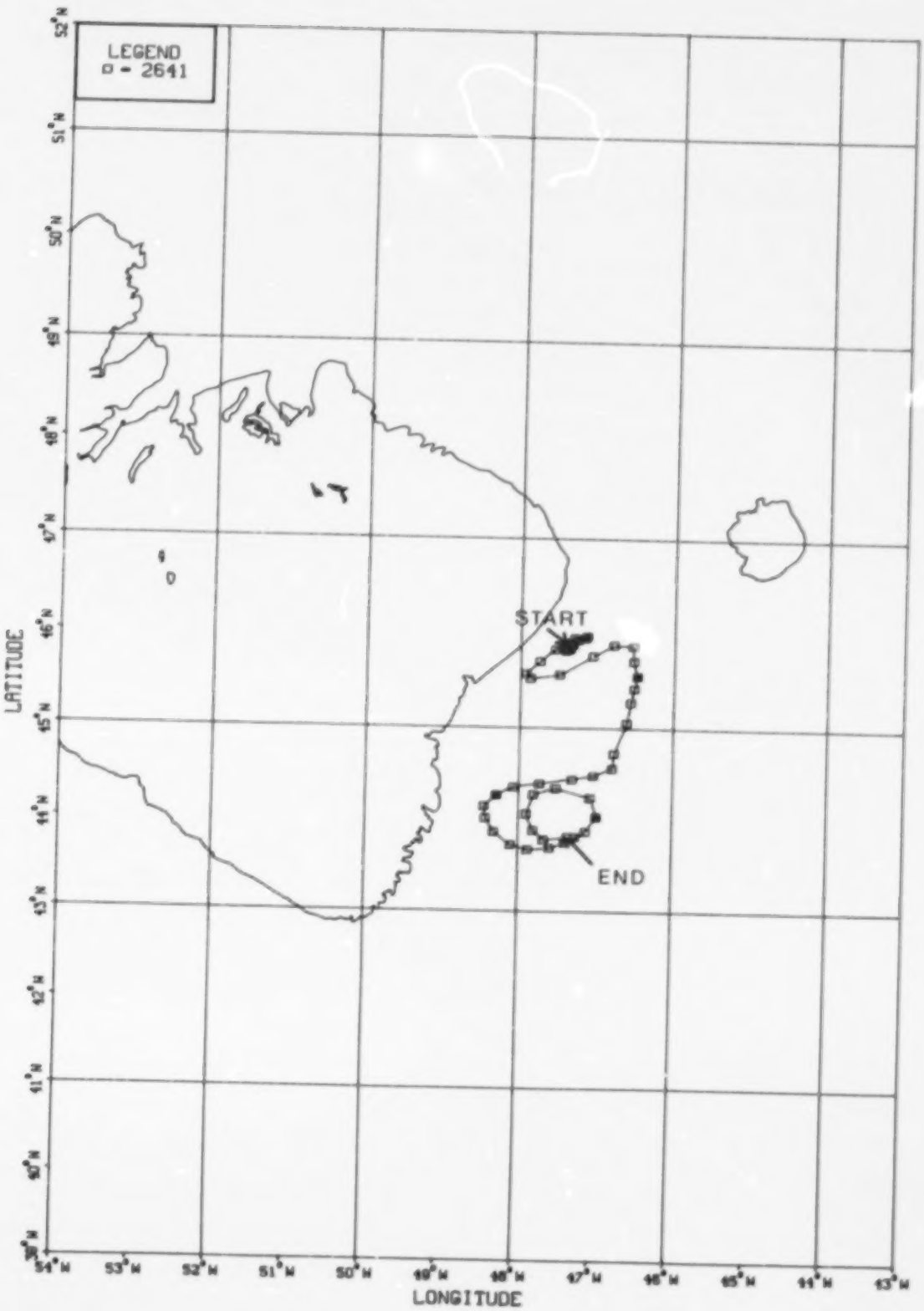
48°W
47°W
46°W
45°W
44°W
43°W
52°N
51°N
50°N
49°N
48°N
47°N
46°N
45°N
44°N
43°N
42°N
41°N
40°N
39°N

# BUOY TRACKS


LEGEND
□ - 2641
START
END
LATITUDE
LONGITUDE
52°N
51°N
50°N
49°N
48°N
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46°N
45°N
44°N
43°N
42°N
41°N
40°N
54°W
53°W
52°W
51°W
50°W
49°W
48°W
47°W
46°W
45°W
44°W
43°W

POOR
QUALITY
ORIGINAL